

**Missouri Department of Natural Resources  
Water Protection Program**

**Total Maximum Daily Loads, or TMDLs**

**for**

**Spring Creek  
Dent County, Missouri**

**DRAFT**

**DRAFT Total Maximum Daily Loads, or TMDLs  
For Spring Creek  
Pollutants: Organic Sediment and Low Dissolved Oxygen**

**Name:** Spring Creek<sup>1</sup>

**Location:** Near Salem in Dent County, Missouri

**Hydrologic Unit Code, or HUC:** 07140102-010003

**Water Body Identification, or WBID:** 1870 (3708)<sup>2</sup>

**Missouri Stream Class:** P<sup>3</sup>

**Designated Beneficial Uses:**

- Livestock and Wildlife Watering
- Protection of Warm Water Aquatic Life
- Protection of Human Health (Fish Consumption)
- Whole Body Contact Recreation – Category B



**Use that is impaired:** Protection of Warm Water Aquatic Life

**Location of Impaired Segment:** Mouth to Section 19, T34N, R5W

**Length of Impaired Segments:** 18 miles

**Location of Impairment within Segment:** Sec.2, T34N, R6W to Hwy 32

**Length of Impairment within Segment:** 7.4 miles

**Pollutants:** Organic Sediment and Low Dissolved Oxygen

**TMDL Priority Ranking:** High

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<sup>1</sup> This creek is incorrectly identified as Spring Branch (Creek) in the 2008 303(d) List of impaired waters. It is identified as Spring Creek on U.S. Geological Survey topographic maps and in Missouri's water quality standards (2009 revision). It will be called Spring Creek in this document.

<sup>2</sup> WBID listed incorrectly as 3708 in the 2008 303(d) List

<sup>3</sup> Class P streams maintain flow even during drought conditions. See Missouri water quality standards 10 Code of State Regulations[CSR] 20-7.031(1)(F). The water quality standards can be found at: [www.sos.mo.gov/adrules/csr/current/10csr/10c20-7.pdf](http://www.sos.mo.gov/adrules/csr/current/10csr/10c20-7.pdf)

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## **1 Introduction**

This Spring Creek Total Maximum Daily Load, or TMDL, is being established in accordance with Section 303(d) of the Clean Water Act. This water quality limited segment near Salem in Dent County, Missouri is included on the U.S. Environmental Protection Agency, or EPA, approved Missouri 2008 303(d) List of impaired waters.

The purpose of a TMDL is to determine the maximum amount of a pollutant (the load) that a water body can assimilate without exceeding the water quality standards for that pollutant. Water quality standards are benchmarks used to assess the quality of rivers and lakes. The TMDL also establishes the pollutant load capacity necessary to meet the Missouri water quality standards established for each water body based on the relationship between pollutant sources and in-stream water quality conditions. The TMDL consists of a wasteload allocation, or WLA, a load allocation, or LA, and a margin of safety, or MOS. The WLA is the portion of the allowable load that is allocated to point sources. The LA is the portion of the allowable load that is allocated to nonpoint sources. The MOS accounts for the uncertainty associated with the model assumption and data limitations.

Section 2 of this report provides background information on the Spring Creek watershed and Section 3 describes potential sources of concern. Section 4 presents the applicable water quality standards, Section 5 describes the water quality problems, and Section 6 describes the modeling that was done to support the TMDL. Sections 7 to 11 present the required TMDL elements (load capacity, WLA, LA, and MOS) and Sections 12 to 15 summarize the follow-up monitoring plan, implementation activities, reasonable assurances and public participation. A summary of the administrative record is presented in Section 16; Appendix A summarizes rainfall data for the watershed; Appendix B displays the available water quality data and Appendix C provides more information on the modeling.

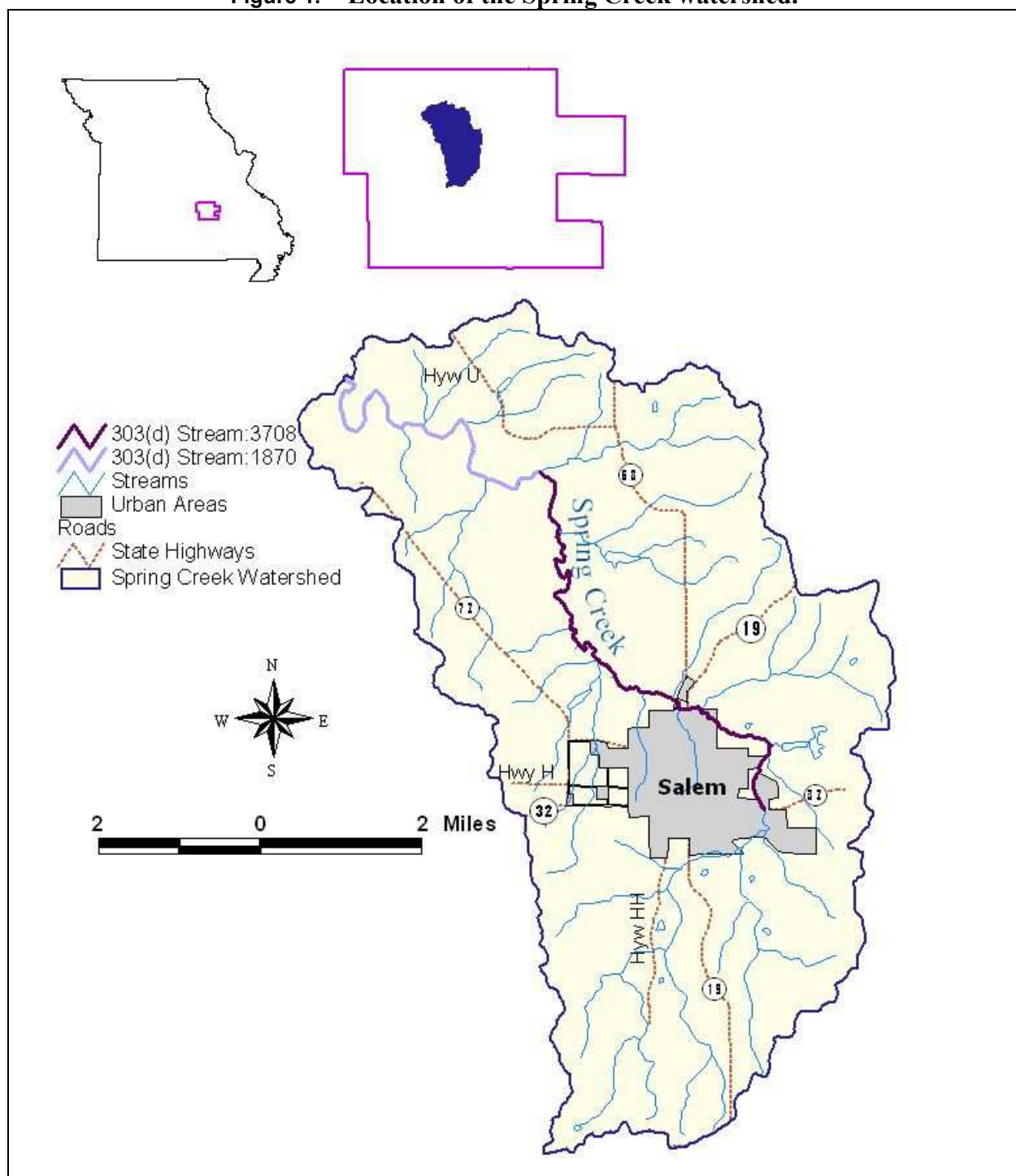
## **2 Background**

This section of the report provides information on Spring Creek and its watershed.

### **2.1 The Setting**

Spring Creek originates south of Salem in Dent County, Missouri, curves around the city to the east and then drains northwest into Dry Fork (Figure 1). Dry Fork in turn feeds into the Meramec River. The classified portion of Spring Creek is fed by several springs and therefore maintains flow all year round. The Spring Creek watershed consists primarily of rural land uses with an area of approximately 44 square miles. In addition to draining the countryside around Salem, Spring Creek also receives all of the storm water runoff from the city. A water quality study in 1985 indicated the stream had problems with deposition of solids (sludge) and low levels of dissolved oxygen downstream from the Salem Wastewater Treatment Facility, or WWTF. As a result, Spring Creek was listed in Missouri's Section 303(d) List of impaired waters in 1994. Originally, Spring Creek was listed for biochemical oxygen demand, or BOD, and volatile suspended solids, or VSS. BOD is the measure of oxygen used by microorganisms to decompose organic matter. VSS is the organic portion of solids that are lost on ignition (heating to 550 degrees Celsius) and approximates the amount of organic matter contained in a water sample.

**Figure 1. Location of the Spring Creek watershed.**



Missouri changed the listed causes of impairment from BOD to dissolved oxygen and from VSS to organic sediment on its 2004/2006 303(d) list to provide a more understandable list to the general public. In addition to these changes, Spring Creek (Water Body Identification, WBID 1870) was resegmented as part of the 2005 revisions to Missouri's water quality standards. This resulted in the original classified segment being divided into two segments, which are now identified as WBIDs 1870 and 3708. The impaired portion of Spring Creek is part of WBID 3708. During preparation of the 2004/2006 303(d) List, the Missouri Department of Natural Resources (Department) proposed to delist Spring Creek due to insufficient data. However, EPA disapproved the request and restored Spring Creek to the list of impaired waters. EPA also revised the length of the impaired segment from 0.3 to 7.4 miles to correspond to the segment's entire classified length.

## **2.2 Population**

The population of the Spring Creek watershed is not directly available. However, the Census reports that the 2007 population for Salem is 4,819 (Census Bureau, 2008). The rural population of the watershed can be roughly estimated based on the proportion of the watershed compared to Dent County. Dent County covers an area of 753 square miles and has a population of 15,276. Since the rural population in Dent County is approximately 10,457 (total county population minus Salem population) and the rural area of the Spring Creek watershed is approximately 40 square miles, the rural population of the watershed is estimated as 555 persons (40 square miles divided by 753 square miles multiplied by 10,457 persons).

## **2.3 Geology and Soils**

The Spring Creek watershed is part of the Salem Plateau, an uplifted area in the center of Missouri's karst topography region. Karst refers to areas in which soluble rock, such as limestone or dolomite, develops caves and underground conduits for water. Water enters these conduits through losing streams<sup>4</sup> and sinkholes<sup>5</sup>. Maps of Dent County show many springs and losing streams and even more sinkholes. These conditions complicate the management of impacts on water quality in both surface and groundwater from activities such as well drilling and on-site septic systems. On the topographic map of Spring Creek, there are eleven springs noted below the WWTF. There are also eight sinkholes below and four above the WWTF along the classified segment.

Spring Creek is in the Nixa-Clarksville-Lebanon-Hobson Soil Association. This soil association contains gentle to moderately steep slopes, somewhat excessively to moderately well-drained soils with a fragipan, cherty subsoil or both. In the bottomlands along Spring Creek are Elsah cherty loam, Sharon silt loam, Pope sandy loam, Sandy alluvial land, Westerville silt loam and Atkins loam. The last two are found further upstream than the others, in general. They all are level or nearly level. Sharon silt loam is prone to flooding and is found in the first bottoms, as is the Pope sandy loam. Westerville silt loam is found in depressions in the floodplains and the Elsah cherty loam is found in the narrow valleys of highly dissected parts of the county.

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<sup>4</sup> A losing stream is one which distributes [loses] thirty percent or more of its flow into a bedrock aquifer. These losses would be during low flow conditions and through natural processes, such as through permeable geologic materials.

<sup>5</sup> A sinkhole or sink is a collapsed portion of bedrock above a void. Sinks may be a sheer vertical opening into a cave, or a shallow depression of many acres.

Coulstone-Clarksville cherty soils, with 2 – 30 percent slopes, are found on the shoulders of slopes and occupy the steep side slopes and narrow ridges in the highly dissected parts of Dent County. These soils are formed in weathered sandstone. Nixa-Clarksville cherty loams, with 5 – 19 percent slopes, are also found on side slopes. The steeper slopes (14 – 19 percent) have a cherty fragipan. Along the broad ridgetops are the Lebanon-Hobson silt loams, with slopes of 2 – 9 that are moderately well-drained, droughty and susceptible to erosion.

Jim Vandike, a registered geologist with the Department, spoke at a public meeting in Salem on July 9, 2007<sup>6</sup>. He indicated the deep bedrock weathering within the watershed makes shallow water vulnerable to surface contaminants and increases the likelihood of water becoming muddy after heavy rainfall. Mr. Vandike stated that Missouri (from north to south) receives 35 to 47 inches of rain per year, has evapotranspiration rates of 26 – 30 inches per year, and that surface water runoff is 5 – 20 inches per year. In the Salem Plateau, the groundwater recharge rate is 6 – 14 inches per year. Rainfall data for the Salem area from 1983 – 2007 is found in Appendix A.

## 2.4 Land Use and Land Cover

The land use and land cover of the Spring Creek watershed is shown in Figure 2 and summarized in Table 1 (MoRAP, 2005). The primary land uses and land covers are grassland (51 percent) and forest (30 percent), with urban areas and herbaceous cover occupying nine and six percent of the watershed area, respectively. The remaining categories comprise less than five percent of the watershed area.

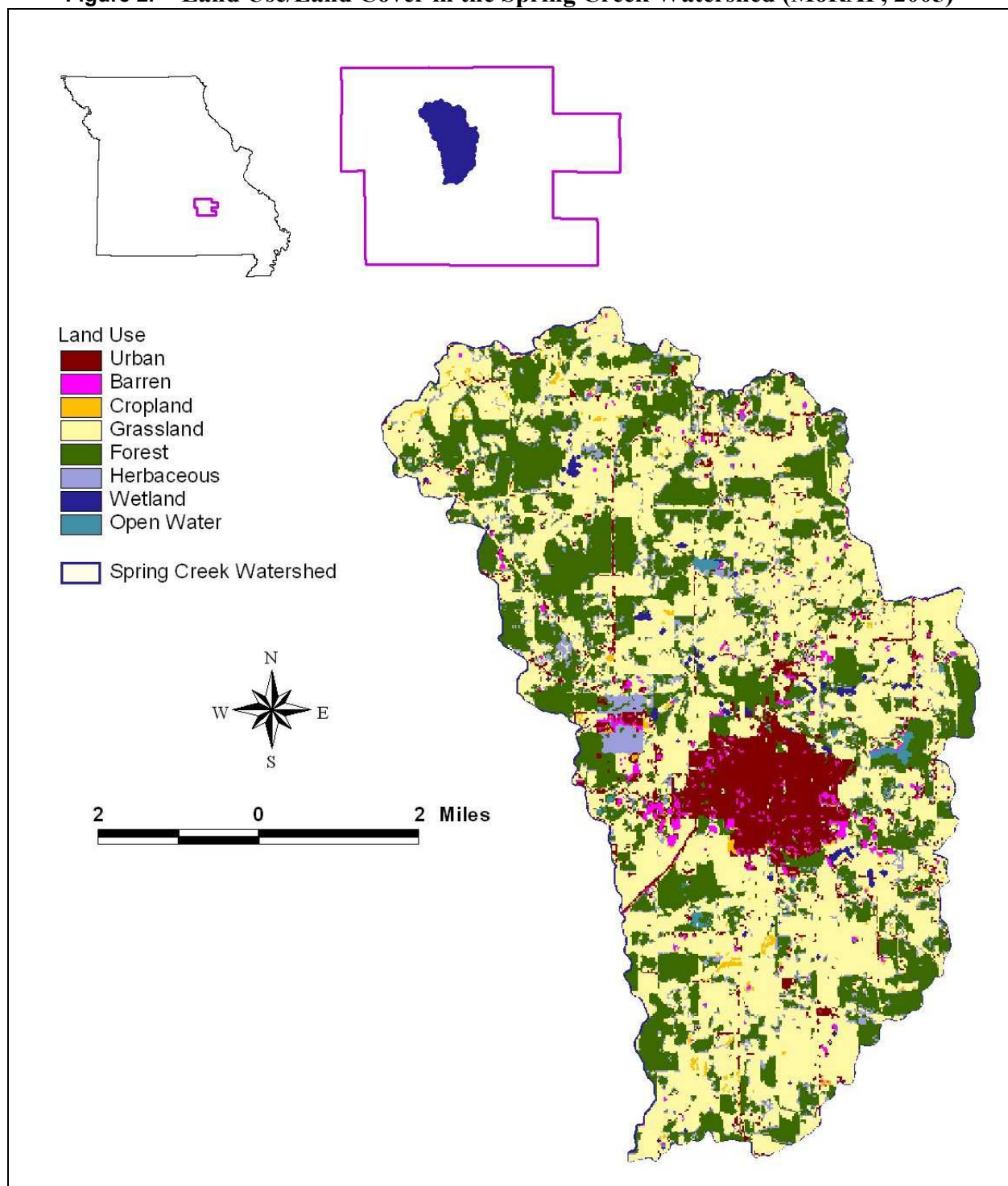
**Table 1. Land Use and Land Cover in Spring Creek Watershed (MoRAP, 2005)**

Land Use/Land Cover	Watershed		Percent
	Area		
	Acres	Square Miles	
Urban	2,527.06	3.95	9.05
Barren	411.87	0.64	1.48
Cropland	246.63	0.39	0.88
Grassland	14,361.09	22.44	51.43
Forest	8,393.15	13.11	30.06
Herbaceous	1,605.24	2.51	5.75
Wetland	212.83	0.33	0.76
Open Water	165.68	0.26	0.59
Total	27,923.55	43.63	100.00

Note: MoRAP = Missouri Resource Assessment Partnership

<sup>6</sup> Most of the information in Mr. Vandike's talk is found in Miller (1997) and Vandike (1996). The well depth information is from well logs and well drilling data on file at the Water Resources Center. Water quality statements are based on 30 years of Mr. Vandike's experience working in the area with groundwater issues.

**Figure 2. Land Use/Land Cover in the Spring Creek Watershed (MoRAP, 2005)**



## 2.5 Defining the Problem

A TMDL is needed for Spring Creek because it is not attaining water quality standards for dissolved oxygen and organic sediment. Dissolved oxygen concentrations have routinely been measured at less than the 5 mg/L minimum criterion and organic sediment has impaired the water body based on observed violations of the narrative criteria described in Section 5.2.2.

Water from Spring Creek was sampled and analyzed by the Department to produce water quality data in July 1985, July 2003, August 2003, and July 2008. The data produced by the Department are of sufficient quality to evaluate compliance with water quality standards and to support TMDL development. The dissolved oxygen results for the four Department surveys are summarized in Table 2 and indicate that a minimum of 11 percent of the dissolved oxygen samples from each survey were less than 5 mg/L. All of the data from these surveys is presented in Appendix B.1 – Department Data.

**Table 2. Summary of dissolved oxygen data for Spring Creek.**

Survey	Number of DO Samples	Minimum (mg/L)	Average (mg/L)	Maximum (mg/L)	Percentage of Samples < 5 mg/L
July 1985	9	4.4	10.0	14.8	11%
July 2003	17	3.4	5.9	12.3	35%
August 2003	20	3	6.4	18.8	40%
July 2008	3	2.8	4.5	6.3	66%

Source: The Missouri Department of Natural Resources

Water from Spring Creek has also been sampled and analyzed monthly since February 2007 by the Salem WWTF to produce water quality data. The data can only be used for screening purposes (i.e., not to evaluate compliance with water quality standards or to support TMDL development), but they appear to corroborate the dissolved oxygen impairments in Spring Creek (Table 3). These data also indicate that the problem exists upstream of the WWTF.

**Table 3. Summary of Salem WWTF instream dissolved oxygen data for Spring Creek. February 2007 through January 2009.**

Location	Number of DO Samples	Minimum (mg/L)	Average (mg/L)	Maximum (mg/L)	Percentage of Samples < 5 mg/L
Upstream of Salem WWTF	24	2.0	6.5	12.8	37.5%
Downstream of Salem WWTF	24	2.4	6.4	9.8	33.3%

Additionally, water from Spring Creek has been sampled and analyzed by Stream Team volunteers. Both the Salem WWTF and the Stream Team data are presented in Appendix B (B.2 and B.3, respectively).

As discussed in Section 4, the low dissolved oxygen problem could be due to one or more of the following:

- Excessive loads of decaying organic solids, as measured by biochemical oxygen demand.
- Too much algae in the stream as a result of excessive phosphorus or nitrogen loading.
- High consumption of oxygen from decaying matter on the streambed.

To better determine the cause of the low dissolved oxygen problem, additional data from Spring Creek were sampled and analyzed in 2008 by Tetra Tech, Inc. under contract with EPA. Some of these data were used in the water quality models for this TMDL (See Section 5.1 and Appendix C).

### **3 Source Inventory**

This section summarizes the available information on significant sources of nutrients and oxygen consuming substances in the Spring Creek watershed. Point (or regulated) sources are presented first, followed by nonpoint (or unregulated) sources. Historic and current water quality data can be found in Appendix B of this document.

#### **3.1 Point Sources**

The term “point source” refers to any discernible, confined and discrete conveyance, such as a pipe, ditch, channel, tunnel or conduit, by which pollutants are transported to a water body. Point sources are regulated through the Missouri State Operating Permit system<sup>7</sup>. By law, the term “point source” also includes: concentrated animal feeding operations, or CAFOs, which are places where animals are confined and fed; storm water runoff from Municipal Separate Storm Sewer Systems (MS4s); and storm water runoff from construction and industrial sites. There are no MS4s or CAFOs located in the Spring Creek watershed, but there are several industrial sites with Missouri storm water permits.

All of the permitted facilities in the Spring Creek watershed are listed in Table 4 and shown in Figure 3. The MFA Bulk Plant is a retail bulk fertilizer distribution center located upstream of the impaired section of Spring Creek. From casual observation on Sept. 9, 2006, all fertilizer looked to be contained with set backs and modest berms so that fertilizer would not be entering the stream. Farther upstream at Highway 32 is the MFA Oil Company which also did not appear to be contributing to poor water quality in Spring Creek. In addition to the MFA Oil Company, the Commons, Seville Care Center and Salem Memorial District Hospital all discharge to tributaries to Spring Creek. These facilities have very small discharges and are not expected to affect Spring Creek. At the very headwaters, the Adams Subdivision Association, Inc. (a small

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<sup>7</sup> The Missouri State Operating Permitting system is Missouri’s program for administering the federal National Pollutant Discharge Elimination System (NPDES) program.

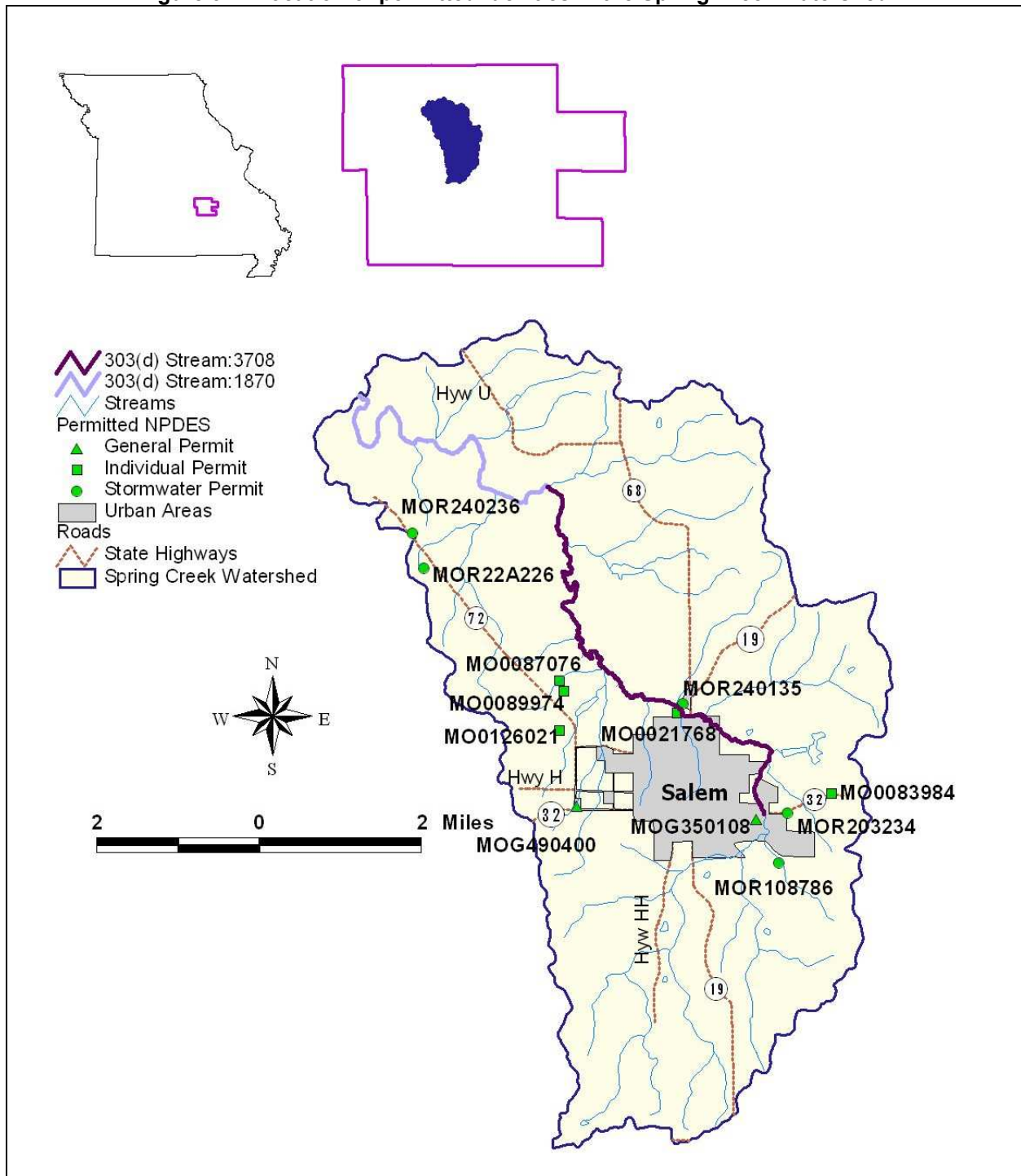
housing development) has a two-cell lagoon with a permit to discharge to a tributary to Spring Creek. In September 2006, both cells were very green with duckweed, but there was no observable discharge and the receiving tributary was dry. The lagoons are a potential source of nutrients (and hence low dissolved oxygen) and need to be maintained. However, since the discharge is very small, the lagoons are not considered a significant source of the impairments.

There are also two facilities with general permits and five facilities with storm water permits that are located in the Spring Creek watershed (Table 4 and Figure 3). General permits (as opposed to site-specific permits) are issued to activities that are similar enough to be covered by a single set of requirements. Storm water permits are issued to activities that discharge only in response to precipitation events.

**Table 4. Permitted Facilities in the Spring Creek watershed.**

<b>Facility ID</b>	<b>Facility Name</b>	<b>Receiving Stream</b>	<b>Design Flow (MGD)</b>	<b>Permit Expiration Date</b>
MOG350108	MFA Bulk Plant	Tributary to Spring Creek	General Permit	2012
MOR240135	MFA Retail Bulk Plant - Salem	Tributary to Spring Creek	Storm water Permit	2014
MOG490400	Salem Ready Mix	Tributary to Spring Creek	General Permit	2011
MOR22A226	Certified Future Forest Products	Spring Creek	Storm water Permit	2014
MOR240236	72 Farm Center LLC	Tributary to Spring Creek	Storm water Permit	Not Available
MOR108786	IDA Building Rightway Homes	Tributary to Spring Creek	Storm water Permit	Not Available
MOR203234	Heartland Metal Finishing	Tributary to Spring Creek	Storm water Permit	2009
MO0083984	Adams Subdivision WWTF	Tributary to Spring Creek	0.009	2009
MO0126021	The Commons	Tributary to Spring Creek	0.001	2007
MO0021768	Salem Municipal WWTF	Spring Creek	0.741	2012
MO0089974	Seville Care Center	Tributary to Spring Creek	0.010	2014
MO0087076	Salem Memorial District Hospital	Tributary to Spring Creek	0.004	2011

**Figure 3. Location of permitted facilities in the Spring Creek watershed**



The Salem Municipal WWTF is the largest permitted facility in the watershed and has a design flow of 0.741 million gallons per day, or MGD. It uses an oxidation ditch to treat domestic wastewater and also has reed beds to further process the sludge before it is land applied outside the watershed (Jack Emery, Salem WWTF, personal communications, Jan. 23, 2009). The Salem WWTF state operating permit was renewed Feb. 9, 2007 and retained BOD and Total Suspended Solids (TSS) effluent limits from the previous permit. Those effluent limits are 45 milligrams per liter (mg/L) weekly average and 20 mg/L monthly average BOD and 45 mg/L weekly average and 30 mg/L monthly average TSS. The Salem WWTF permit includes instream monitoring of Spring Creek, both upstream and downstream of the WWTF. The permit expires Feb 8, 2012.

Illicit (illegal) straight pipe discharges of household wastewater are also potential point sources in rural areas. These are discharges straight into streams or land areas and are different than illicitly connected sewers. There is no specific information on the number of illicit straight pipe discharges of household wastewater in the Spring Creek watershed.

### **3.2 Nonpoint Sources**

Nonpoint sources include all other categories not classified as point sources. Potential nonpoint sources contributing to low dissolved oxygen problems in the Spring Creek watershed include runoff from agricultural areas, runoff from urban areas, onsite wastewater treatment systems, and various sources associated with riparian habitat conditions. Each of these is discussed further in the following sections.

#### **3.2.1 Runoff from Agricultural Areas**

Lands used for agricultural purposes can be a source of nutrients and oxygen-consuming substances. Accumulation of nitrogen and total phosphorus on cropland occurs from decomposition of residual crop material, fertilization with chemical and manure fertilizers, atmospheric deposition, wildlife excreta and irrigation water. The 2005 land use and land cover data indicate there are 246 cropland acres in the watershed, which is a relatively small proportion (less than one percent) of the entire watershed area (Table 1). Similarly, less than one percent of the riparian buffer is classified as cropland (Table 5).

Countywide data from the National Agricultural Statistics Service (USDA, 2002) were combined with the land cover data for the Spring Creek watershed to estimate there are approximately 2,800 cattle in the watershed<sup>8</sup>. The cattle are most likely located on the approximately 14,361 acres of grassland/pastureland in the watershed, and runoff from these areas can be potential sources of nutrients and oxygen consuming substances. For example, animals grazing in pasture areas deposit manure directly upon the land surface and, even though a pasture may be relatively large and animal densities low, the manure will often be concentrated near the feeding and watering areas in the field. These areas can quickly become barren of plant cover, increasing the possibility of erosion and contaminated runoff during a storm event. In addition, when pasture

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<sup>8</sup> According to the National Agricultural Statistics Service there are approximately 35,000 head of cattle in Dent County (USDA, 2002). According to the 2005 Missouri Resource Assessment Partnership there are 278 square miles of grasslands in Dent County (MoRAP, 2005). These two values result in a cattle density of approximately 126 cattle per square mile of grasslands. This density was multiplied by the number of grassland acres in the Spring Creek watershed to estimate the number of cattle in the watershed.

land is not fenced off from the stream, cattle or other livestock may contribute nutrients to the stream while walking in or adjacent to the water body. The density of cattle in the Spring Creek watershed (65 cattle per square mile) suggests they are a potentially significant source of pollutants. The National Agricultural Statistics Service also reports there were 523 hogs and pigs, 401 sheep and lambs, 1,091 poultry layers, and 25,200 poultry broilers in Dent County in 2002. No data are available to estimate the number of these other livestock that might be located in the Spring Creek watershed.

### **3.2.2 Runoff from Urban Areas**

Storm water runoff from urban areas can also be a significant source of nutrients and oxygen-consuming substances. Lawn fertilization can lead to high nutrient loads and pet wastes can contribute both nutrient loads and oxygen consuming substances to the aquatic environment. For example, phosphorus loads from residential areas can be comparable to or higher than loading rates from agricultural areas (Reckhow et al., 1980; Athayde et al., 1983). Leaking or illicitly connected sewers can also be a significant source of pollutant loads within urban areas. Storm runoff from urban areas such as parking lots and buildings is also warmer than runoff from grassy and woodland areas, which can lead to higher temperatures that lower the dissolved oxygen saturation capacity of the stream. Excessive discharge of suspended solids from urban areas can also lead to streambed siltation problems.

Since approximately ten percent of the Spring Creek watershed is classified as urban (including the city of Salem), and a significant portion of that area is adjacent to the impaired segment, urban storm water runoff is considered a potentially significant source of the pollutants of concern.

### **3.2.3 Onsite Wastewater Treatment Systems**

Onsite wastewater treatment systems (e.g., individual home septic systems) that are properly designed and maintained should not serve as a source of contamination to surface waters. However, onsite wastewater treatment systems do fail for a variety of reasons. When these treatment systems fail hydraulically (surface breakouts) or hydrogeologically (inadequate soil filtration) there can be adverse effects to surface waters. Failing septic systems are sources of nutrients that can reach nearby streams through both surface runoff and ground water flows.

The exact number of onsite wastewater systems in the Spring Creek watershed is unknown. However, as discussed in Section 2.2, the estimated rural population of the Spring Creek watershed is approximately 555 persons. Based on this population and an average density of 2.4 persons per household, there may be approximately 231 onsite wastewater treatment systems in the watershed. Information from the Dent County Health Center suggests that a minimal amount of complaints have been registered during the past two years regarding failing systems (Roma Jones, Dent County Health Center, personal communication, Dec. 11, 2008). However, Russell Lilly from the Department of Health and Senior Services provided information at a public meeting in May 2007 indicating 63 percent of the households in Dent County have onsite septic systems (3,876 of 6,115 households) and, based on statewide surveys, 70 percent of these are likely failing (See Section 13.2, Implementation-Nonpoint Sources). EPA also reports that the statewide failure rate of onsite wastewater systems in Missouri is 30 to 50 percent (EPA, 2002). Failing onsite wastewater treatment systems therefore should be considered as a potentially significant source of the pollutants of concern in the Spring Creek watershed. This is especially

true given the karst topography of the region which can rapidly transport pollutants from the surface to subsurface.

#### **3.2.4 Riparian Habitat Conditions**

Riparian<sup>9</sup> habitat conditions can also have a strong influence on in-stream dissolved oxygen. Wooded riparian buffers are a vital functional component of stream ecosystems and are instrumental in the detention, removal and assimilation of nutrients, soil and other pollutants before they reach the stream. Therefore a stream with good riparian habitat is better able to moderate the impacts of high nutrient loads than a stream with poor habitat. Wooded riparian buffers can also provide shading that reduces stream temperatures and increases the dissolved oxygen saturation capacity of the stream.

On the other hand, riparian buffers can be sources of natural background material that possibly could contribute to the dissolved oxygen problem. For example, leaf fall from vegetation near the water's edge, aquatic plants, and drainage from organically rich areas like swamps and bogs are all natural sources of material that consumes oxygen.

As indicated in Table 5, almost half of the land in the Spring Creek riparian corridor is classified as grassland, which might include pasture areas (MoRAP, 2005). Grassland provides limited riparian area compared to wooded areas, very little shading and can also be associated with livestock activity. Another 12 percent of the riparian corridor is classified as impervious<sup>10</sup> and urban areas, which do not provide adequate buffers for pollution (filtration) and shading and can contribute high nutrient loads associated with lawn fertilization and pet waste. Riparian habitat conditions, therefore, should be considered as one possible component of water quality problems in Spring Creek.

**Table 5. Percentage Land Use/Land Cover within Riparian Buffer (MoRAP, 2005)**

<b>Land Use/Land Cover*</b>	<b>Spring Creek</b>
Urban	12.23
Barren	0.51
Cropland	0.76
Grassland	48.03
Forest	30.43
Herbaceous	7.00
Wetland	1.03
Open Water	0.01

\*Land Use/Land Cover within 30-meter riparian buffer

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<sup>9</sup> A riparian corridor (or zone or area) is the linear strip of land running adjacent to a stream bank.

<sup>10</sup> Impervious surfaces are roads, rooftops and parking lots that do not allow water to infiltrate into the ground where it can be filtered, cleaned and replenish the groundwater.

## **4 Applicable Water Quality Standards and Numeric Water Quality Targets**

The purpose of developing a TMDL is to identify the maximum amount of a pollutant that a water body can receive and still achieve water quality standards. Water quality standards are therefore central to the TMDL development process. Under the Clean Water Act, every state must adopt water quality standards to protect, maintain, and improve the quality of the nation's surface waters (U.S. Code Title 33, Chapter 26, Subchapter III (U.S. Code, 2009)). Missouri's Water Quality Standards at 10 CSR 20-7.031 contains three main components: designated beneficial uses, water quality criteria that protect those uses (both numeric and narrative), and antidegradation requirements. These three components collectively ensure the quality of Missouri's waters is protected and maintained.

### **4.1 Designated Beneficial Uses**

The designated beneficial uses of Spring Creek, WBID 1870, are:

- Livestock and Wildlife Watering
- Protection of Warm Water Aquatic Life
- Protection of Human Health (Fish Consumption)
- Whole Body Contact Recreation – Category B

The use that is impaired is Protection of Warm Water Aquatic Life. Spring Creek is designated as Category B for the whole body contact recreation use, which means it has places deep enough for total immersion (i.e., swimming), but they may be on private lands or inaccessible to the public. Designated beneficial uses and stream classifications for Missouri may be found in the Water Quality Standards at 10 CSR 20-7.031(1)(C), (1)(F) and Table H. Copies of 10 CSR 20-7.031 are available from the Missouri Secretary of State (CSR, 2005).

### **4.2 Numeric Criteria**

Missouri's water quality criteria that relate to dissolved oxygen and organic sediment are presented in the following sections. The sections also provide brief descriptions regarding why dissolved oxygen and organic sediment are important to water quality, how these parameters are measured, and how they are related to other water quality parameters.

#### **4.2.1 Low Dissolved Oxygen**

Dissolved oxygen is one of the most critical characteristics of our surface waters because fish, mussels, macroinvertebrates, and all other aquatic life utilize dissolved oxygen to create energy and metabolize food; without sufficient dissolved oxygen little aquatic life would survive. The water quality criterion for all Missouri streams except cold water fisheries require a daily minimum of 5 mg/L dissolved oxygen (10 CSR 20-7.031 Table A (CSR, 2005)).

Dissolved oxygen in streams is affected by several factors including water temperature, the amount of decaying matter in the stream, turbulence at the air-water interface, and the amount of photosynthesis occurring in plants within the stream. Decaying matter can come from wastewater effluent as well as agricultural and urban runoff and is typically measured in-stream as biochemical oxygen demand, or BOD. Decaying matter can also accumulate on the bottom of a stream and cause sediment oxygen demand, or SOD. SOD is a combination of all of the oxygen-consuming processes that occur at or just below the sediment/water interface. SOD is

partly due to biological processes and partly due to chemical processes. Most of the SOD at the surface of the sediment is due to the biological decomposition of organic material and the bacterially facilitated nitrification of ammonia, while the SOD several centimeters into the sediment is often dominated by the chemical oxidation of species such as iron, manganese, and sulfide (Wang, 1980; Walker and Snodgrass, 1986).

Nitrogen and phosphorus can also contribute to dissolved oxygen problems because they can accelerate algae growth in streams. Algae growth in streams is most frequently assessed based on the amount of chlorophyll *a* in the water. The algae consume dissolved oxygen during respiration at night and have the potential to remove large amounts of dissolved oxygen from the stream. The breakdown and decomposition of dead, decaying algae also removes oxygen from the water column. Dissolved oxygen, BOD, nitrogen, and phosphorus data for Spring Creek are summarized in Appendix B.

#### **4.2.2 Organic Sediment**

Spring Creek is also listed for organic sediment, but there are no specific numeric criteria for this pollutant. The general, or narrative, criteria that apply may be found in the general criteria section of the water quality standards at 10 CSR 20-7.031(3)(A) and (C) (CSR, 2005). Here it states:

- Waters shall be free from substances in sufficient amounts to cause the formation of putrescent, unsightly, or harmful bottom deposits or prevent full maintenance of beneficial uses.
- Waters shall be free from substances in sufficient amounts to cause unsightly color or turbidity, offensive odor, or prevent full maintenance of beneficial uses.

Wastewater treatment facilities often discharge high levels of organic sediment (as opposed to sand and silt) into receiving streams. Organic sediments are a water quality problem because they can settle onto the bottom of a stream and smother natural substrates (materials in the streambed), aquatic invertebrate animals (like mayfly larvae and crayfish) and fish eggs. High amounts of organic sediment also contribute to sludge on the stream bottom, which has an offensive odor in addition to being unsightly.

Through previous studies, the Department has found that limiting BOD from domestic wastewater treatment facilities will often result in corresponding reductions in organic sediment that will eliminate an organic sediment impairment.

#### **4.3 Antidegradation Policy**

Missouri's water quality standards include EPA's "three-tiered" approach to antidegradation, which may be found at 10 CSR 20-7.031(2) (CSR, 2005).

Tier 1 – Protects existing uses and a level of water quality necessary to maintain and protect those uses. Tier 1 provides the absolute floor of water quality for all waters of the United States. Existing in-stream water uses are those uses that were attained on or after Nov. 28, 1975, the date of EPA's first Water Quality Standards Regulation.

Tier 2 – Protects and maintains the existing level of water quality where it is better than applicable water quality criteria. Before water quality in Tier 2 waters can be lowered, there must be an anti-degradation review consisting of: (1) a finding that it is necessary to accommodate important economical or social development in the area where the waters are located; (2) full satisfaction of all intergovernmental coordination and public participation provisions; and (3) assurance that the highest statutory and regulatory requirements for point sources and best management practices for nonpoint sources are achieved. Furthermore, water quality may not be lowered to less than the level necessary to fully protect the “fishable/swimmable” uses and other existing or beneficial uses.

Tier 3 – Protects the quality of outstanding national and state resource waters, such as waters of national and state parks, wildlife refuges, and exceptional recreational or ecological significance. There may be no new or increased discharges to these waters and no new or increased discharges to tributaries of these waters that would result in lower water quality.

#### **4.4 Water Quality Targets**

There are several water quality targets for this TMDL. To achieve the dissolved oxygen minimum criterion target of 5 mg/L, reductions in biochemical oxygen demand will be needed. A QUAL2K water quality model will be used to determine the 5-day carbonaceous biochemical oxygen demand wasteload allocation protective of the minimum criterion. To ensure the dissolved oxygen minimum criterion target of 5 mg/L is met, reductions in total suspended solids, total nitrogen and total phosphorus will also be targeted as they affect dissolved oxygen levels in a stream system. Total suspended solids as organic sediment particles (algae or sludge) consume oxygen during decomposition and can contribute to sediment oxygen demand (SOD). Excess nutrients (i.e., total nitrogen and total phosphorous) can cause excessive algae growth in a stream and contribute to the organic matter load which consumes dissolved oxygen in the water column and sediment upon decomposition. The targets for TSS, total nitrogen, and total phosphorous will be based on load duration curves, which determine the TMDL for each of these parameters at every flow probability (Section 7).

### **5 TMDL Development**

This section details the data collection and modeling efforts conducted in support of the TMDL for Spring Creek

#### **5.1 Data Collection**

To more fully understand the cause of the low dissolved oxygen problem, additional data from Spring Creek were sampled and analyzed in 2008 by Tetra Tech, Inc. under contract with EPA. These data are of sufficient quality to evaluate compliance with water quality standards and to support TMDL development. The data were collected in accordance with required quality assurance procedures and Department sampling protocols (Tetra Tech, 2008a; 2008b; MDNR, 2005). The location of the sampling sites in May and September 2008 are provided in Figure 4 and the data are summarized in Table 6 and Table 7.

**Table 6. Summary of Spring Creek water quality data collected on May 29, 2008.**  
**Average flow during this event was 2.7 cubic feet per second (cfs).**

Sampling Location (Time)	Location	Chlorophyll a (µg/L)	CBOD5 (mg/L)	Nitrogen, Ammonia (mg/L)	Nitrogen, TKN (mg/L)	Nitrogen, NO2+NO3	DO (mg/L)	pH	Temp. (°C)	TP (mg/L)	TSS (mg/L)
SP-1 (8:30AM)	2.5 mi above WWTF	7	1.00	0.23	0.03	0.11	6.31	6.40	17.38	0.006	10
SP-2 (9:45AM)	0.1 mi above WWTF	5	1.00	0.16	0.03	0.31	5.55	6.95	18.26	0.006	12
SP-3 (9:25AM)	Salem WWTF Effluent	No Data	1.00	0.01	0.03	15.30	6.78	7.40	19.01	2.500	5
SP-4 (11:30AM)	1.0 mi below WWTF	3	1.00	0.17	0.03	3.50	5.67	7.46	No Data	0.450	6
SP-5 (2:00PM)	2.2 mi below WWTF	2	1.00	0.13	1.10	2.40	7.64	7.22	17.22	0.280	17
SP-6 (3:00PM)	3.8 mi below WWTF	40	2.50	0.17	0.03	0.00	0.97	6.99	16.19	0.270	20

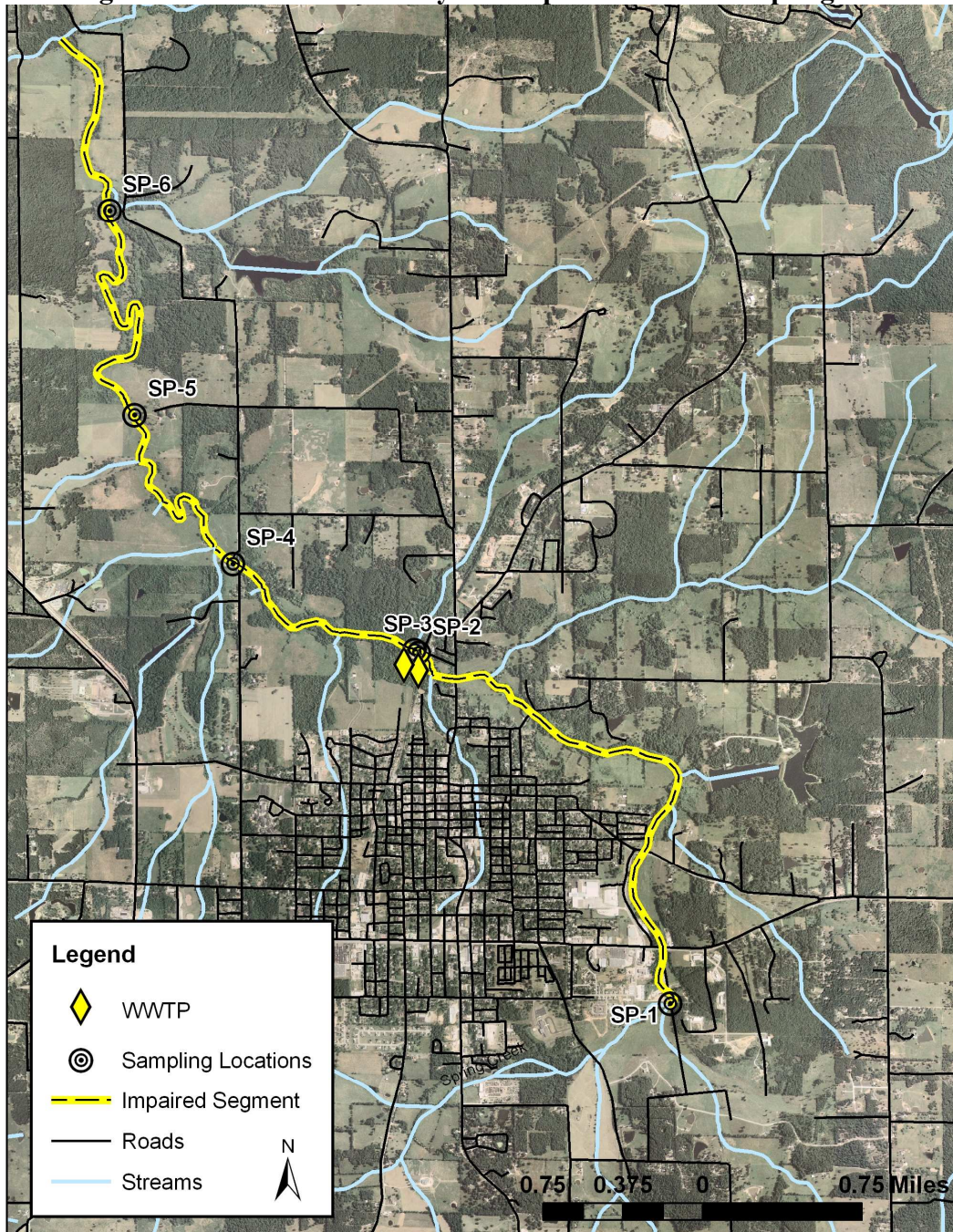
Notes: µg/L = micrograms per liter; CBOD5 = Carbonaceous Biochemical Oxygen Demand (5 days); TKN = Total Kjeldahl Nitrogen; NO2+NO3 = Nitrite + Nitrate; DO = Dissolved Oxygen; Temp. = Temperature in degrees Celsius; TP = Total Phosphorus; TSS = Total Suspended Solids; DL = Detection Limit.

**Table 7. Summary of Spring Creek water quality data collected on September 3, 2008.**  
**Average flow during this event was 9.3 cfs.**

Sampling Location (Time)	Location	Chlorophyll a (µg/L)	CBOD5 (mg/L)	Nitrogen, Ammonia (mg/L)	Nitrogen, TKN (mg/L)	Nitrogen, NO2+NO3	DO (mg/L)	pH	Temp. (°C)	TP (mg/L)	TSS (mg/L)
SP-1 (8:50AM)	2.5 mi above WWTF	1	1.00	0.13	0.03	0.00	10.04	7.67	20.39	0.006	2.5
SP-2 (9:30AM)	0.1 mi above WWTF	4	5.40	0.05	0.35	0.05	4.53	6.92	22.62	0.050	7
SP-3 (10:00AM)	Salem WWTF Effluent	2	1.00	0.14	0.10	0.12	3.65	7.47	22.42	0.050	2.5
SP-4 (10:15AM)	1.0 mi below WWTF	No Data	1.00	0.05	0.41	3.70	5.19	7.46	24.58	2.700	2.5
SP-5 (11:00AM)	2.2 mi below WWTF	< DL	1.00	0.05	0.10	0.87	5.51	7.40	21.35	0.750	2.5
SP-6 (11:30AM)	3.8 mi below WWTF	1	2.30	0.05	0.26	0.65	6.22	7.54	21.19	0.570	21

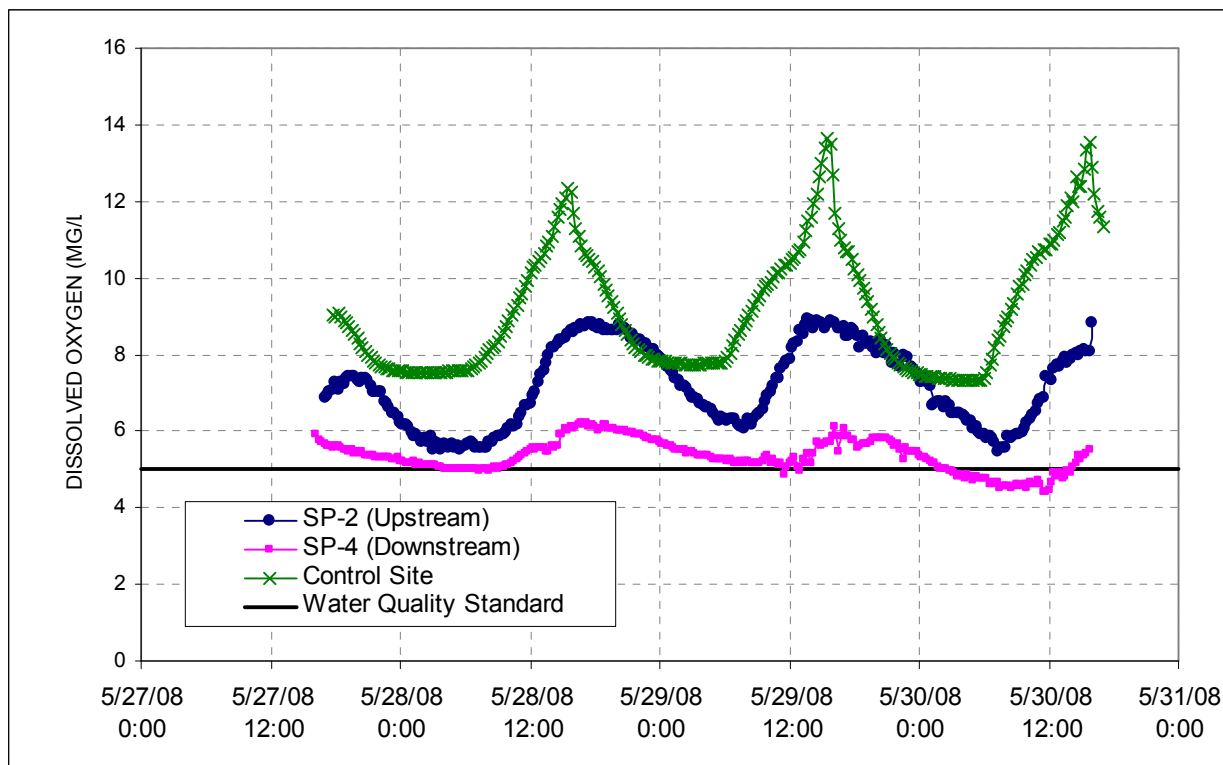
Notes: µg/L = micrograms per liter; CBOD5 = Carbonaceous Biochemical Oxygen Demand (5 days); TKN = Total Kjeldahl Nitrogen; NO2+NO3 = Nitrite + Nitrate; DO = Dissolved Oxygen; Temp. = Temperature in degrees Celsius; TP = Total Phosphorus; TSS = Total Suspended Solids; DL = Detection Limit.

**Figure 4. Location of the May and September 2008 sampling sites**



Data loggers were deployed at stations SP-2 and SP-4 from May 27 to May 30, 2008 and dissolved oxygen data from the loggers were recorded every 15 minutes; those data are presented in Figure 5<sup>11</sup>.

**Figure 5. Continuous dissolved oxygen data observed at SP-2, SP-4, and the control sampling location during late May 2008.**



There are several issues worth noting from a review of the data collected from Spring Creek in May and September 2008:

- One location (SP-6, 3.8 miles downstream of the Salem WWTF) had an observed dissolved oxygen concentration below the water quality standard of 5 mg/L during the May 2008 sampling. Chlorophyll *a* at this site was 40 micrograms per liter ( $\mu\text{g/L}$ ) on the same date.
- Only one location on Spring Creek (SP-2, 0.1 miles upstream of the WWTF) had dissolved oxygen below 5 mg/L during the September 2008 sampling event.

<sup>11</sup> High flows [associated with the aftermaths of Hurricane Ike] precluded the deployment of the data loggers for the September 2008 sampling event. The data loggers were intended to sample dissolved oxygen data every fifteen minutes over a three day period.

- Total phosphorous, or TP, concentrations in the effluent of the WWTF were 2.5 mg/L in May 2008 and 2.7 mg/L in September 2008. This caused instream TP concentrations to be elevated for several miles downstream.
- The nitrite plus nitrate, also known as NO<sub>2</sub>+NO<sub>3</sub>, concentration in the effluent of the WWTF in May 2008 was 15.3 mg/L. This caused instream NO<sub>2</sub>+NO<sub>3</sub> concentrations to be elevated for several miles downstream. Effluent NO<sub>2</sub>+NO<sub>3</sub> in September was reported as only 0.12 mg/L, although concentrations downstream of the WWTF were still elevated.
- The 15 minute dissolved oxygen data indicate a diurnal pattern, with concentrations higher during the late afternoon and lowest during early morning. There were several early morning periods at SP-4 where the dissolved oxygen data dropped below 5 mg/L.

These data suggest that nutrient loads originating within Salem could be contributing to excessive algal growths downstream. The excessive algal growths, in turn, may be causing dissolved oxygen to fall below 5 mg/L late at night when the algae are consuming, but not producing, dissolved oxygen. Large amounts of algae may also be contributing to low dissolved oxygen, high BOD, and high SOD when they decay.

While the Salem WWTF is certainly contributing nutrients to the dissolved oxygen impairment, the data suggest there are also dissolved oxygen problems upstream of the WWTF. Other sources of oxygen demanding substances and nutrients, such as those detailed in Section 3, must also be contributing to the impairment. Concentrations of other parameters in the Salem WWTF effluent (e.g., ammonia and BOD) were well below permit limits during both the May and September sampling and were likely not directly contributing to the observed low dissolved oxygen.

The causes of the dissolved oxygen impairments upstream of the WWTF are less clear. There are several permitted facilities upstream of the Salem WWTF, but their cumulative flow is less than four percent of the Salem WWTF flow. The upstream impairments may be due to excessive algal growths or high nonpoint source loads of BOD. Nonpoint sources in the Spring Creek watershed include runoff from agricultural and urban areas, onsite wastewater treatment systems, and diminished riparian areas.

The low dissolved oxygen and high organic sediment are the result of high nutrient loads from the Salem WWTF which trigger algal growth which in turn causes excessive oxygen consumption during early morning hours and deposits decaying algal debris on the stream bottom. The problem is exacerbated by nonpoint nutrient sources and loss of riparian areas.

## 5.2 TMDL Modeling<sup>12</sup>

Two different models were used in the development of the Spring Creek TMDL. The QUAL2K model was used to calculate the allowable carbonaceous biochemical oxygen demand (CBOD<sub>5</sub>) load to Spring Creek that attains the minimum dissolved oxygen criterion of 5 mg/L. Load

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<sup>12</sup> EPA Region 7 performed the modeling for this TMDL

duration curves were used to generate secondary target loads for total suspended solids and nutrients that would not cause or contribute to violations of the minimum dissolved oxygen criterion.

Dissolved oxygen in streams is determined by the factors of photosynthetic productivity, respiration (autotrophic and heterotrophic), reaeration, and temperature. These factors are influenced by natural and anthropogenic conditions within a watershed. Generally, reaeration is based on the physical properties of the stream and on the capacity of water to hold dissolved oxygen. This capacity is mainly determined by water temperature with colder water having a higher saturation concentration for dissolved oxygen. In a review of variables and their importance in dissolved oxygen modeling Nijboer and Verdonchot (2004) categorized the impact of a number of variables on oxygen depletion. For this TMDL, the effects of temperature and the physical aspects of the stream itself were discounted. Pollutants which result in oxygen concentrations below saturation are:

- fine particle size of bottom sediment
- high nutrient levels (nitrogen and phosphorus)
- suspended particles of organic matter

Because these three variables vary to a large extent based on anthropogenic influences they are appropriate targets for a TMDL written to address an impairment of low dissolved oxygen.

Since fine particle sized sediment and suspended particles of organic matter are derived from similar loading conditions of terrestrial and stream bank erosion, this TMDL will have as one of its allocations total suspended solids (see Appendix D for discussion of development of total suspended solids targets). To address nutrient levels, the EPA nutrient ecoregion reference concentrations were used. For the ecoregion where Spring Creek is located (Level III, Ozark Highlands), the reference concentration for total nitrogen<sup>13</sup> is 0.289 mg/L, and the reference concentration for total phosphorus is 0.007 mg/L (EPA 2001a and EPA 2001b). This TMDL will not specifically target chlorophyll *a* as a wasteload allocation, but will use a linkage between nutrient concentrations and chlorophyll response to achieve the ecoregion reference concentrations.

### 5.2.1 QUAL2K

An essential component of developing a TMDL is establishing a relationship between the source loadings and the resulting water quality. For this TMDL, the relationship between the source loadings of biochemical oxygen demand and nutrients on dissolved oxygen is generated by the water quality model QUAL2K (Chapra et al., 2007).

QUAL2K is supported by EPA and it and its predecessor (QUAL2E) have been used extensively for TMDL development and point source permitting issues across the country, especially for dissolved oxygen studies. QUAL2K is well accepted within the scientific community because of its proven ability to simulate the processes important to dissolved oxygen conditions within streams. The QUAL2K model is suitable for simulating the hydraulics and water quality

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<sup>13</sup> Total Kjeldahl nitrogen and nitrate plus nitrite as nitrogen

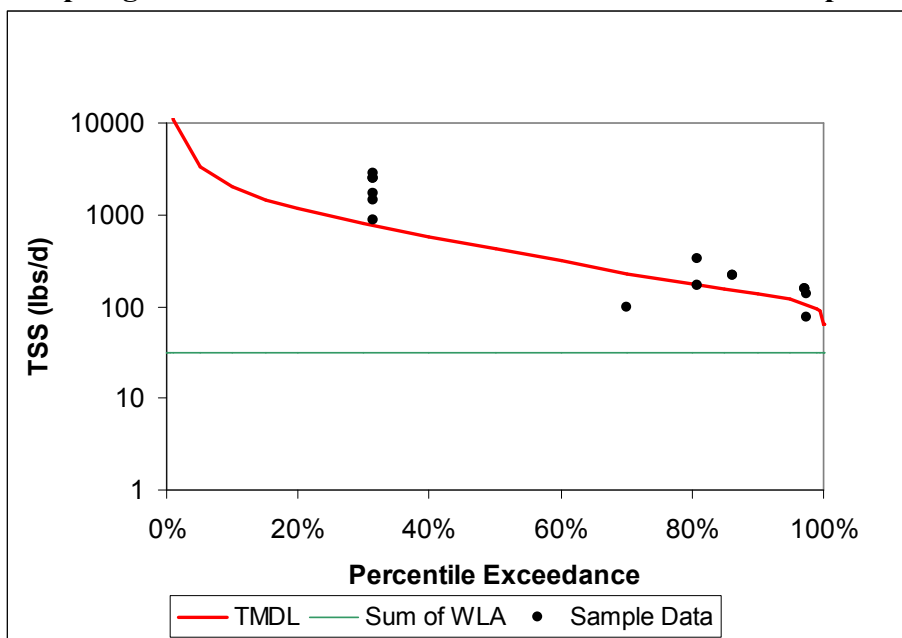
conditions of a small river. It is a one-dimensional model with the assumption of a completely mixed system for each computational cell. QUAL2K assumes that the major pollutant transport mechanisms, advection and dispersion, are significant only along the longitudinal direction of flow. The model allows for multiple waste discharges, water withdrawals, tributary flows, and incremental inflows and outflows. The processes employed in QUAL2K address nutrient cycles, algal growth, and dissolved oxygen dynamics. Once the QUAL2K model was setup and calibrated for Spring Creek, a series of scenarios were run to evaluate the pollutant load reductions needed to achieve the dissolved oxygen criteria.

Tetra Tech data (Section 5) from the 2008 stream water quality sampling at Spring Creek were used to develop the QUAL2K model described in Appendix C.1. Though there were two sampling events (May 29 and Sept. 3) conducted in 2008, the data collected during September were not used for model validation because this event was not representative of the critical flow condition. The wasteload allocation for Spring Creek for CBOD<sub>5</sub>, calculated to maintain the DO criterion of 5.0 mg/L instream, is 3.347 mg/L. That is equal to 18.06 pounds per day CBOD<sub>5</sub>.

### 5.2.2 Load Duration Curves

A TMDL load duration curve for total suspended solids (TSS) was developed by targeting the 25<sup>th</sup> percentile of total suspended sediment measurements (U.S. Geological Survey, or USGS, non-filterable residue) in the geographic region in which Spring Creek is located (see Appendices D - F for the methodology, a list of sites and data). The 25<sup>th</sup> percentile of these data is 5 mg/L TSS. Figure 6 shows the TSS load duration curve.

**Figure 6. Spring Creek TMDL Load Duration Curve for Total Suspended Solids**

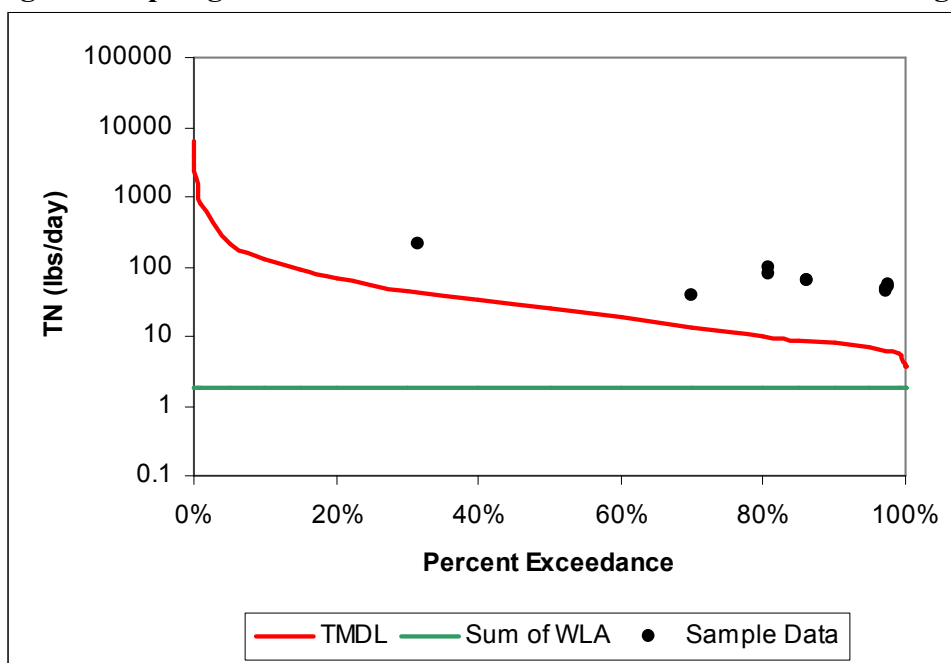


To develop load duration curves for total nitrogen and total phosphorus, a method similar to that used for total suspended solids was employed. First, total nitrogen and total phosphorus

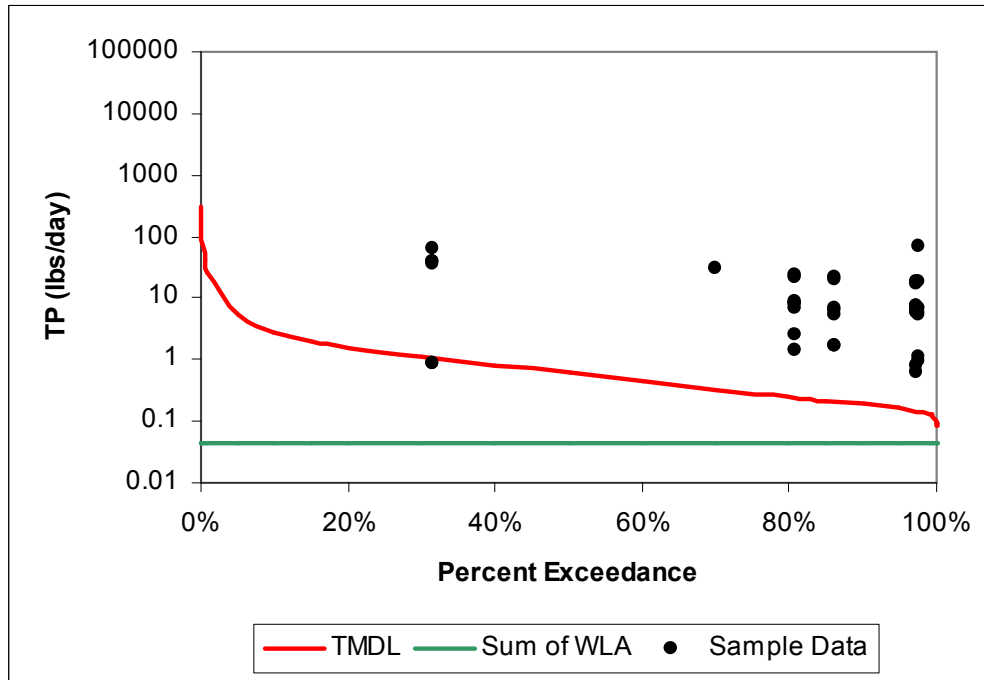
measurements were collected from USGS sites in the vicinity of the impaired stream. These data were adjusted such that the median of the measured data was equal to the ecoregion reference concentration. This was accomplished by subtracting the difference of the data median and the reference concentration. Where this would result in a negative concentration, the data point in question was replaced with the minimum concentration seen in the measured data. This resulted in a modeled data set which retained much of the original variability seen in the measured data. This modeled data was then regressed as instantaneous load versus flow. The resultant regression equation was used to develop the load duration curve.

To develop the TMDL expression of maximum daily loads, the background discharge at the stream outlet was modified from the traditional approach using synthetic flow estimation. Since the design flow from permitted facilities would overwhelm the background natural low flow, the sum of permitted volumes was added to the derived stream discharge at all percentiles of flow to take into account the increases in flow volume as well as pollutant load. The TMDL curves in the load duration curves flatten at low flow because at these lower flows the TMDL target is dominated by the point source flow. Figures 7 and 8 show total nitrogen (TN) and total phosphorous (TP) load duration curves, respectively.

**Figure 7. Spring Creek TMDL Load Duration Curve for Total Nitrogen**



**Figure 8. Spring Creek TMDL Load Duration Curve for Total Phosphorous**



## 6 Calculation of Load Capacity

Load capacity, or LC, is defined as the greatest amount of loading of a pollutant that a water body can receive without violating water quality standards. This load is then divided among the sum of the point source (wasteload allocation, or WLA) and nonpoint source (load allocation, or LA) contributions to the stream with an allowance for an explicit margin of safety. If the margin of safety is implicit, no numeric allowance is necessary. The load capacity of the stream can therefore be expressed in the following manner:

$$LC = \sum WLA + \sum LA + MOS$$

The wasteload allocation and load allocation are calculated by multiplying the appropriate stream flow in cubic feet per second, or cfs, by the appropriate pollutant concentration in milligrams per liter, or mg/L. A conversion factor of 5.395 is used to convert to the units (cfs and mg/L) to pounds per day (lbs/day).

$$(stream\ flow\ in\ cfs)(maximum\ allowable\ pollutant\ concentration\ in\ mg/L)(5.395) = pounds/day$$

Critical conditions must be considered when the load capacity is calculated. Dissolved oxygen levels that threaten the integrity of aquatic communities generally occur during low flow periods, so these periods are considered the critical conditions for the purpose of the dissolved oxygen model (QUAL2K).

## 7 Waste Load Allocation (Point Source Loads)

The wasteload allocation is the portion of the load capacity that is allocated to existing or future point sources of pollution. The sum of the design flows of all site-specific permitted dischargers with Missouri State Operating Permits (Table 4) in the Spring Creek watershed, including the Salem Wastewater Treatment Facility, is 0.765 million gallons per day. This does not include general or storm water permits which would not have a discharge during critical low flow conditions.

To meet the nutrient and total suspended solids critical condition load capacities outlined in this TMDL, the sum of permitted facility wasteload allocations was calculated by using nutrient ecoregion reference concentrations and 25<sup>th</sup> percentile total suspended solids concentrations, and the sum of the design flows of all permitted facilities in the watershed. The resulting sum of all permitted facility wasteload allocations are 1.85 lbs/day for TN, 0.04 lbs/day for TP, and 31.99 lbs/day for TSS. These values were calculated using nutrient and TSS ecoregion reference concentrations and the sum of the design flows of the permitted facilities in the Spring Creek watershed.

New wasteload allocations for the Salem Wastewater Treatment Facility were calculated through the modeling process and are shown in Table 8. The wasteload allocations for total nitrogen, total phosphorus and total suspended solids were derived from the load duration curves at low flow, when inputs are set at the facility design flow of 1.15 cubic feet per second. The wasteload allocation for carbonaceous biochemical oxygen was derived from the QUAL2K modeling that resulted in meeting water quality standards.

**Table 8. Waste Load Allocations for Salem Wastewater Treatment Facility**

Pollutant	Concentration Limits	WLA at Design Flow (1.15 cfs)
TN	0.289 mg/L	1.79 lbs/day
TP	0.007 mg/L	0.04 lbs/day
TSS	5 mg/L	31 lbs/day
CBOD <sub>5</sub>	3.3 mg/L	20.5 lbs/day

The other permitted facilities in the Spring Creek watershed each discharge an insignificant volume of effluent compared to the Salem Wastewater Treatment Facility and are also unlikely to discharge during the critical low flow periods. Their wasteload allocations will therefore remain equal to existing permit limits.

## 8 Load Allocation (Nonpoint Source Load)

The load allocation includes all existing and future nonpoint sources and natural background contributions (40 CFR § 130.2(g)). The load allocations for the Spring Creek TMDL are for all nonpoint sources of total nitrogen, total phosphorus, and total suspended solids, which could include loads from agricultural lands, runoff from urban areas, livestock, and failing onsite

wastewater treatment systems. Table 9 summarizes load allocations, or LAs, for total nitrogen, total phosphorous, and total suspended solids at various flow conditions. As an example, at the 50<sup>th</sup> percentile flow exceedance the TMDL loads are set to 24.76 lbs/day for TN, 0.60 lbs/day for TP, and 428.29 lbs/day for TSS. The LAs were calculated by removing the WLAs for permitted facilities within the watershed at critical low flow conditions. The resulting LAs for the 50<sup>th</sup> percentile flow exceedance are 22.91 lbs/day for TN, 0.55 lbs/day for TP, and 396.31 lbs/day for TSS.

**Table 9. TMDL Allocations for Spring Creek**

Percentile flow exceedance	Flow (cfs)	TN TMDL (lbs/d)	TN LA (lbs/d)	TN sum WLA (lbs/d)	TP TMDL (lbs/d)	TP LA (lbs/d)	TP sum WLA (lbs/d)	TSS TMDL (lbs/d)	TSS LA (lbs/d)	TSS sum WLA (lbs/d)	Explicit MOS (lbs/d)
95%	4.5	6.96	5.11	1.85	0.17	0.12	0.04	120.38	88.39	31.99	0.00
90%	5.1	8.02	6.17	1.85	0.19	0.15	0.04	138.72	106.73	31.99	0.00
70%	8.4	13.09	11.24	1.85	0.32	0.27	0.04	226.49	194.50	31.99	0.00
50%	15.9	24.76	22.91	1.85	0.60	0.55	0.04	428.29	396.31	31.99	0.00
30%	29.3	45.72	43.87	1.85	1.11	1.06	0.04	791.03	759.04	31.99	0.00
10%	74.8	124.69	122.84	1.85	2.82	2.78	0.04	2017.81	1985.82	31.99	0.00
5%	122.9	217.53	215.68	1.85	5.24	5.19	0.04	3314.48	3282.49	31.99	0.00

## 9 Margin of Safety

A margin of safety is required in the TMDL calculation to account for uncertainties in scientific and technical understanding of water quality in natural systems. The margin of safety is intended to account for such uncertainties in a conservative manner. Based on EPA guidance, the margin of safety can be achieved through one of two approaches:

- (1) Explicit - Reserve a portion of the load capacity as a separate term in the TMDL.
- (2) Implicit - Incorporate the margin of safety as part of the critical conditions for the wasteload allocation and the load allocation calculations by making conservative assumptions in the analysis.

An implicit margin of safety was incorporated into the TMDL based on conservative assumptions applied to the QUAL2K model and used in the development of the TMDL load duration curves. Among the conservative approaches used was to calculate wasteload allocations by targeting the 25<sup>th</sup> percentile of total suspended solids concentrations in the geographic region in which Spring Creek is located, and to establish wasteload allocations for the Salem Wastewater Treatment Facility under critical low flow conditions when discharge from this facility will dominate the stream flow.

## **10 Seasonal Variation**

Federal regulations at 40 CFR §130.7(c)(1) require that TMDLs take into consideration seasonal variation in applicable standards. The Spring Creek TMDL addresses seasonal variation in two ways. One is by identifying a loading capacity that is protective of the critical low flow period sampled in May 2008. Dissolved oxygen concentrations did not meet water quality standards during the May 2008 sampling and were lower (i.e., more critical) than those recorded during September 2008. QUAL2K TMDL development for low dissolved oxygen during critical low-flow conditions are expected to be protective year round.

The second way in which the Spring Creek TMDL takes seasonal variation into account is through the use of load duration curves. Load duration curves represent the allowable pollutant load under different flow conditions and across all seasons. The results obtained using the load duration curve method are more robust and reliable over all flows and seasons when compared with those obtained under critical low-flow conditions.

## **11 Monitoring Plan for TMDLs Developed under Phased Approach**

Post-TMDL monitoring will be scheduled and carried out by the Department about three years after the TMDL is approved, or in a reasonable period of time following any TMDL compliance schedule outlined in the Salem WWTF state operating permit and the application of any new effluent limits. The Salem WWTF permit was renewed on February 9, 2007 with an in-stream monitoring requirement, both upstream and downstream of the WWTF, to further determine the impact of the facility discharge on Spring Creek. Data to be collected monthly in Spring Creek include temperature, dissolved oxygen, pH and ammonia. In light of concerns regarding excess nutrients entering the stream, nutrient monitoring may be added to this permit to characterize the effluent contribution to in-stream nutrients. Also, the local Stream Team gathered dissolved oxygen data at five sites along Spring Creek during the 2007 to 2008 school year. These two sources of data (permittee instream monitoring and volunteer monitoring) will be used for screening purposes, to compare the stream's current condition with future, post-TMDL, conditions. The wastewater treatment plant in-stream monitoring data and volunteer monitoring data are included in Appendices B.2. and B.3., respectively.

Additionally, the Department will routinely examine physical habitat, water quality, invertebrate community, and fish community data collected by other state and federal agencies in order to assess the effectiveness of TMDL implementation. One example is the Resource Assessment and Monitoring Program administered by the Missouri Department of Conservation. This program randomly samples streams across Missouri on a five to six year rotating schedule.

## **12 Implementation Plans**

Since low dissolved oxygen is an issue in Spring Creek both upstream and downstream of the Salem Wastewater Treatment Facility, addressing the sources of impairment in Spring Creek will require developing nonpoint source, as well as point source, controls in the watershed. However, due to issues regarding low dissolved oxygen as a natural background condition, the Department may develop revised dissolved oxygen criteria for Spring Creek and similar streams during the future reviews of the Water Quality Standards. The Department acknowledges that, should

revised criteria be developed, a revised Spring Creek TMDL may be necessary. It also acknowledges that the revised criteria may result in no difference for Spring Creek and that new loading calculations may not differ or offer relief from what is currently contained in this TMDL.

### **12.1 Point Sources**

This TMDL will be implemented partially through permit action. When it was last renewed, the operating permit for the Salem WWTF (MO-0021768) retained the BOD and TSS effluent limits from the previous permit. Those limits are 45 mg/L weekly average and 20 mg/L monthly average BOD and 45 mg/L weekly average and 30 mg/L monthly average TSS. Design flow in the permit is 0.741 MGD.

Wasteload allocations developed for this TMDL will be used to derive new effluent limitations for carbonaceous biochemical oxygen demand (CBOD<sub>5</sub>) and total suspended solids (TSS) that reduce organic sediment and are protective of the dissolved oxygen criterion and aquatic life use in Spring Creek. The Department anticipates numeric and narrative water quality criteria will be met after the new effluent limits for CBOD<sub>5</sub> and TSS have been applied to the Salem WWTF. Implementation of these effluent limits will require continued proper operation and maintenance of the facility, and may include upgrades and improvements to address reductions in CBOD<sub>5</sub> and TSS. Upgrades will also include the elimination of Outfall #002 that is planned for the next permit cycle. Effluent monitoring for nutrient species and in-stream monitoring for dissolved oxygen, temperature, pH, ammonia and chlorophyll *a* will also be required on the Salem Wastewater Treatment Plant operating permit. Additional monitoring and analysis may be conducted by either the Department or the city to determine whether the dissolved oxygen minimum criterion of 5 mg/L found in 10 CSR 20-7.031, Table A is appropriate or if a site-specific dissolved oxygen criterion is required. Any such evaluation would likely coincide with the Department's triennial review of the Water Quality Standards, when a new dissolved oxygen criterion may be promulgated. If it is determined that the current water quality criterion for dissolved oxygen is appropriate, the wasteload allocations from the TMDL will be implemented. If it is determined not to be appropriate, and a new dissolved oxygen criterion is promulgated, then new wasteload allocations will be calculated and implemented.

If post-TMDL monitoring indicates that point source reductions are not achieving the desired improvements in water quality, the Department will reevaluate the TMDL for further appropriate actions. These actions may include additional permit conditions on the Salem WWTF (including effluent limits for total nitrogen and total phosphorus), revised permit conditions on other permitted facilities and further control of nonpoint sources through a nonpoint source management plan.

Permitted facilities within the watershed will be inspected prior to next permit renewal to determine if best management practices and permit conditions ensure the facilities are not contributing nutrients or oxygen demanding pollutants to Spring Creek. The inspections will include an assessment of the condition of the facilities and whether upgrades or additional measures are necessary.

## 12.2 Nonpoint Sources

Because low dissolved oxygen was also recorded upstream of the Salem WWTF, nonpoint sources of oxygen consuming substances and nutrients must also be considered. To address this component of the TMDL, an attempt was made to start a watershed group in Salem. Many citizens were involved, including the mayor, the sewer superintendent and other city managers, as well as local residents, landowners, business owners, Stream Teams and farmers. Four public meetings were held, one each in March, April, May and July 2007. During a brainstorming session in April 2007, the group identified the following nonpoint source issues as possible anthropogenic contributors to low dissolved oxygen and nutrients in Spring Creek:

### 1) Nutrients from fertilizer/manure

- Fertilizer runoff from lawns, fields and pastures
- Manure runoff from lawns (pets), animal shelter, barn lots and pastures.
- “Direct deposit” from cattle in the creek
- Fertilizer/compost storage at businesses along the creek (lawn care, fertilizer distribution, garden centers)

### 2) Nutrients from leaky on-site septic systems

- Failure of the systems
- Straight pipes to the creek
- Septic tanks not maintained (pumped out regularly)

### 3) Warm water temperatures

- Inadequate or nonexistent riparian, or buffer, zone along the creek
- Hot storm water runoff (from summer pavement)
- Silt (erosion from development, road construction and farmland)

Several people in the group were of the opinion that the low dissolved oxygen conditions in Spring Creek are caused by the natural seasonal cycle of rain and summer dry spells. Especially in late summer and early fall, they said, the water is at its lowest and in some places there may only be standing pools, so the oxygen levels will be low. That time of year, however, is when the Department typically collects data for dissolved oxygen to determine attainability of the protection of warm water aquatic life designated use. It is considered the “critical period” because summer low flow conditions are when aquatic life are most stressed and susceptible to the effects of pollutants. Additionally, if dissolved oxygen levels are adequate during the critical low flow periods and can sustain a balanced and diverse aquatic community, conditions will certainly be adequate during the rest of the year. The group, however, wanted the Department to monitor dissolved oxygen year round. As a result, the local Stream Team volunteered to gather that data. The local Stream Team joined with a Stream Team from the Missouri University of Science and Technology and monitored five sites on Spring Creek every other month through the 2007-08 school year. These teams are continuing to monitor Spring Creek in 2008-09. Data already collected by these volunteers are shown in Appendix A.3.

On May 29, 2007, the featured speaker, Russell Lilly from the Department of Health and Senior Services, discussed issues with on-site septic systems. He stated that 63 percent of the households in Dent County have on-site septic (3876 of 6115 households). Based on statewide

surveys, up to 70 percent of these are likely failing. Untreated septic system waste adds nutrients and pathogens to the environment. This problem is compounded by the karst topography in the region (see Section 2.2), making the installation and location of any septic system important to the success of the system and to local water quality in both surface and ground water.

On July 9, 2007, Jim Vandike spoke about the hydrology of Spring Creek (See Section 2.2). Some of the local citizens were concerned that the water table under Salem was dropping. Mr. Vandike assured these citizens that, based on available data, groundwater levels in the Salem area today are not appreciably different than they were when the first wells were drilled in the area. Mr. Vandike went on to talk about the karst topography in the area, including springs and losing streams, and he related the story of a well-closing in Salem. It turned out that several of the Salem city officials present knew about this well closing and were interested to hear more of the details. As a point of interest, he stated that private wells in and around Salem range from less than 200 feet deep to more than 500 feet deep, depending on location. Also, drilling a new well has approximately a one in three chance of producing water poorly suited for domestic use, not in terms of well yield but in terms of quality.

In the end, the citizens present at the public meetings decided against forming a watershed group to address the nonpoint source issues. However, the local Stream Team, in cooperation with Missouri University of Science and Technology, continues to monitor Spring Creek. Dent County 4-H youth and members of the Bonebrake Center of Nature and History's youth group, the Ozark Kids' Connection, conduct periodic litter pick-ups on a tributary to Spring Creek. They also strive to educate people on how citizens can contribute to the health of the Spring Creek watershed through stream-related activities and educational programs with local schools (sponsored by the Bonebrake Center).

### **13 Reasonable Assurances**

The Department has the authority to issue and enforce Missouri State Operating Permits. Inclusion of effluent limits determined from the wasteload allocations established by the TMDL into a state permit, along with effluent monitoring reported to the Department, should provide a reasonable assurance that in-stream water quality standards will be met. The Department will work with the city of Salem to discuss treatment plant upgrades and funding options and will issue a permit reflective of the water quality standards that must be met.

In most cases, "Reasonable Assurance" in reference to TMDLs relates only to point sources. As a result, any assurances that nonpoint source contributors of low dissolved oxygen will implement measures to reduce their contribution in the future will not be found in this section. Instead, discussion of reduction efforts relating to nonpoint sources can be found in the "Implementation" section of this TMDL.

### **14 Public Participation**

EPA regulations require that TMDLs be subject to public review (40 CFR 130.7). Before finalizing TMDLs, the Department's Water Protection Program notifies the public that a comment period is open for 45 days by placing a Public Notice, the draft TMDL and the

associated TMDL Information Sheet on the Department's website, making them available to anyone with access to the Internet. Public notice announcements are also distributed via mail and electronic mail to stakeholders in the watershed, or other potentially impacted parties. In this case, those receiving the public notice announcement included the Missouri Clean Water Commission, Salem WWTF, the City of Salem, the Dent County Commission, the Dent County Soil and Water Conservation District, the Water Quality Coordinating Committee, 18 Stream Team volunteers in the watershed, the two state legislators representing the Spring Creek watershed and those who attended the public meetings in 2007. After the comment period closes, the Department reviews all comments, writes and sends responses to the comments and edits the TMDL as appropriate. It then submits the TMDL and supporting documents along with the comments and responses to EPA's Region 7 office in Kansas City, KS, for their review.

## **15 Administrative Record and Supporting Documentation**

An administrative record on the Spring Creek TMDL has been assembled and is being kept on file with the Missouri Department of Natural Resources. It includes the following:

- Salem WWTF State Operating Permit MO-0021768.
- Stream Survey Sampling Report, Salem Wastewater Treatment Plant, Spring Creek, Salem, Missouri, Dent County, July 22-23 and August 27-28, 2003, by Environmental Services Program (two 48-hour water quality studies).
- Continuous monitoring data, 5/27 – 5/30/08, for two sites on Spring Creek and one on the reference creek.
- QUAL2K input and output files.
- Spring Creek TMDL Information Sheet.
- Public notice announcement.
- Comments received and the Department's response to those comments.

## References

- Athayde, D., P. Shelley, E. Driscoll, D. Gaboury and G. Boyd, 1983. Results of the Nationwide Urban Runoff Program, Volume I.
- Census Bureau. 2008. 2007 Population Estimates. Retrieved November 6, 2008, <http://www.census.gov/>
- Chapra, S.C., G.J. Pelletier, and H. Tao, 2007. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality, Version 2.07: Documentation and Users Manual. Civil and Environmental Engineering Dept., Tufts University, Medford, MA.
- Miller, Don E., and Vandike, James E., 1997. Groundwater Resources of Missouri: Missouri Department of Natural Resources, Division of Geology and Land Survey, Missouri State Water Plan Series Vol, II, Water Resources Report no. 46, 210 pages.
- CSR (Code of State Regulations). 2005. Missouri Secretary of State Web page. Title 10 - Department of Natural Resources. Division 20 – Clean Water Commission. Chapter 7 – Water Quality. 10 CSR 20-7.031 - Water Quality Standards. <http://www.sos.mo.gov/adrules/csr/current/10csr/10c20-7.pdf>
- MoRAP (Missouri Resource Assessment Program). 2005. Land Use/Land Cover Data. Retrieved April 26, 2007, from [www.msdis.missouri.edu](http://www.msdis.missouri.edu)
- Nijboer, R.C. and P.F.M. Verdonchot. 2004. Variable selection for modelling effects of eutrophication on stream and river ecosystems. *Ecol. Model.* 177:17-39.
- Reckhow, K. H., M. N. Beaulac, and J. R. Simpson, 1980. Modeling Phosphorous Loading and Lake Response Under Uncertainty: A Manual and Compilation of Export Coefficients. EPA-440/5-8-011, U.S. Environmental Protection Agency, Washington, D.C.
- U.S. Code. 2009. Title 33 of the U.S. Code. Retrieved February 19, 2009, from [www.gpoaccess.gov/uscode/](http://www.gpoaccess.gov/uscode/)
- USEPA (U.S. Environmental Protection Agency). 2000. Ambient Water Quality Criteria Recommendations: Rivers and Streams in Nutrient Ecoregion XI. U.S. Environmental Protection Agency, Washington DC. EPA 822-B-00-020.
- \_\_\_\_\_. 2002. Onsite Wastewater Treatment System Manual. EPA/625/R-00/008. U.S. Environmental Protection Agency, Office of Water, Washington, DC, and Office of Research and Development, Cincinnati, OH. February 2002.

USDA (U.S. Department of Agriculture). 2002. National Agriculture Statistics Service. Retrieved February 19, 2009, from [www.nass.usda.gov/](http://www.nass.usda.gov/)

USDA, Soil Conservation Service and Forest Service in cooperation with Missouri Agricultural Experiment Station, March 1971, Soil Survey, Dent County, Missouri.

Vandike, James E., 1996. The hydrology of Maramec Spring, Missouri Department of Natural Resources, Division of Geology and Land Survey, Water Resources Report no. 55, 104 pages.

Walker, R.R., and Snodgrass, W.J., 1986. Model for sediment oxygen demand in lakes: *Journal of Environmental Engineering*, v. 112, no. 1, p. 25-43.

Wang, W., 1980. Fractionation of sediment oxygen demand: *Water Research*, v. 14, p. 603-612.

## Appendix A

### Spring Creek Rainfall Data, 1983-2007

The National Weather Service reporting station for Salem is operated by the National Forest Service at their office just south of the Highway 32-19 junction. This is nearly in the center of Spring Creek watershed. There are more than a hundred years of precipitation and temperature data available for Salem. The data for 25 years (1983 through 2007) are shown below. Also shown are the first six months of 2008, in which precipitation is well ahead of normal for the year.

The results show that, while it varies considerably, precipitation has actually increased in the Salem area during the last 25 years. The long-term rolling average (apparently updated about every 10 years) went from 39.59 inches in the early 1980s to 42.10 inches in 1990s to the current value of 43.90 inches.

The letter “m” denotes missing data, so the value is the minimum possible precipitation. In the past 25 years, the data shows less than average precipitation in 11 years (including the years of missing data) and greater than average precipitation in 14 years, including 5 years that had missing data.

**Table A-1. Rainfall Data for Salem, Missouri. 1983-2007**

Year	Precip (in)	Departure from long term average (in)	Long term average (in)
1983	38.03 m	-1.56 m	
1984	34.81 m	-4.78 m	
1985	46.81 m	+7.22 m	39.59
1986	36.96	-2.63	
1987	41.64 m	+2.05 m	
1988	41.17	+1.58	
1989	30.60	-8.99	
1990	62.38	+22.79	
1991	48.53 m	+8.94 m	
1992	30.83 m	-8.76 m	
1993	57.86	+15.76	
1994	43.68 m	+1.58 m	
1995	44.66 m	+2.56 m	
1996	52.76	+10.66	42.10
1997	53.51	+11.41	
1998	38.36	-3.74	
1999	35.71	-6.39	
2000	32.47 m	-9.63 m	
2001	40.71	-1.39	
2002	53.02	+9.12	
2003	35.04 m	-8.86 m	

**Table A-1 (cont). Rainfall Data for Salem, Missouri. 1983-2007**

2004	44.44	+0.54	43.90
2005	42.70	-1.20	
2006	45.25	+1.35	
2007	48.54	+4.64	
2008 through June, 37.16 in.			

**Source:** Climatological Data Annual Summary Missouri 1983, Vol 87, no. 13, through Climatological Data Annual Summary Missouri 2006, Vol. 110, no. 13, National Oceanic and Atmospheric Administration, National Climatic Data Center, Ashville, North Carolina. Monthly Climatological Data Missouri January 2007 (vol. 111, no. 01) through Climatological Data Missouri December 2007 (vol. 111, no. 12).

## Appendix B – Spring Creek Water Quality Data

### B.1 – Department Data

Org	Site	Site Name	Year	Month	Day	Time	Flow	C	DO	pH	SC	TKN	NH3N
MoDNR	1870/9.0	Spring Cr. 0.5 mi.bl. Salem WWTF	1985	7	18			20	4.4	7.8			
MoDNR	1870/9.45	Spring Cr. 50 yds bl. Salem WWTF	1985	7	18			20	6.5	7.8			
MoDNR	1870/4.5	Spring Cr. 5.0 mi.bl. Salem WWTF	1985	7	18	1815	4	21	13.8				
MoDNR	1870/9.5	Salem WWTF	1985	7	18								
MoDNR	1870/8.5	Spring Cr. 1.0 mi.bl. Salem WWTF	1985	7	18	605	1.5	20	6.8	7.7			
MoDNR	1870/9.6	Spring Cr. 0.1 mi.ab. Salem WWTF	1985	7	18		0.75	21	10.6	7.8			
MoDNR	1870/9.6	Spring Cr. 0.1 mi.ab. Salem WWTF	1985	7	18	1530		27	14.8				
MoDNR	1870/9.45	Spring Cr. 50 yds bl. Salem WWTF	1985	7	18	1545		26	11.8				
MoDNR	1870/8.5	Spring Cr. 1.0 mi.bl. Salem WWTF	1985	7	18	1740		22	7.2	7.3			
MoDNR	1870/9.0	Spring Cr. 0.5 mi.bl. Salem WWTF	1985	7	18	1555		29	13.8				
MoDNR	1870/9.5	Salem WWTF	1985	7	19								
MoDNR	1870/9.6	Spring Cr. 0.1 mi.ab. Salem WWTF	2003	7	22	545	0.29	24.5	3.5	7.5	136	0.55	0.07
MoDNR	1870/9.5	Salem WWTF	2003	7	22	610	0.98	24	3.8	7.6	749		
MoDNR	1870/8.5	Spring Cr. 1.0 mi.bl. Salem WWTF	2003	7	22	620	1.34	22	4.5	8	473	0.74	0.01499
MoDNR	1870/4.5	Spring Cr. 5.0 mi.bl. Salem WWTF	2003	7	22	615	4.24	23	5	7.4	429	0.76	0.03
MoDNR	1870/5.3	Spring Cr. 4.2 mi.bl. Salem WWTF	2003	7	22	550	3.19	23.5	4.7	7.4	439	0.76	0.04
MoDNR	1870/9.6	Spring Cr. 0.1 mi.ab. Salem WWTF	2003	7	22	1310		27	12.3	8.2	100	0.86	0.01499
MoDNR	1870/9.5	Salem WWTF	2003	7	22	1245		27	4.8	7.6	766	0.27	0.01499
MoDNR	1870/8.5	Spring Cr. 1.0 mi.bl. Salem WWTF	2003	7	22	1400		27	7.1	8.3	477	0.02499	0.01499
MoDNR	1870/5.3	Spring Cr. 4.2 mi.bl. Salem WWTF	2003	7	22	1300		25	7.3	7.8	426	0.61	0.01499
MoDNR	1870/4.5	Spring Cr. 5.0 mi.bl. Salem WWTF	2003	7	22	1315		24	6.5	7.7	427	0.23	0.03
MoDNR	1870/9.6	Spring Cr. 0.1 mi.ab. Salem WWTF	2003	7	23	530		22	3.4	7.5	288	0.48	0.01499
MoDNR	1870/9.5	Salem WWTF	2003	7	23	550		22	4.4	7.4	807		
MoDNR	1870/8.5	Spring Cr. 1.0 mi.bl. Salem WWTF	2003	7	23	605		20	4.4	6.5	508	0.87	0.03
MoDNR	1870/5.3	Spring Cr. 4.2 mi.bl. Salem WWTF	2003	7	23	635		21	5.1	6.8	401	0.61	0.06
MoDNR	1870/4.5	Spring Cr. 5.0 mi.bl. Salem WWTF	2003	7	23	620		21	5.5	7.3	396	0.51	0.01499
MoDNR	1870/9.6	Spring Cr. 0.1 mi.ab. Salem WWTF	2003	7	23	1300		25	10.5	8.3	377	0.53	0.01499
MoDNR	1870/9.5	Salem WWTF	2003	7	23	1245	0.84	27	4.8	7.5	840	1.01	0.01499
MoDNR	1870/8.5	Spring Cr. 1.0 mi.bl. Salem WWTF	2003	7	23	1320		21	6.65	7.8	509	0.75	0.01499

Org	Site	Site Name	Year	Month	Day	Time	Flow	C	DO	pH	SC	TKN	NH3N
MoDNR	1870/5.3	Spring Cr. 4.2 mi.bl. Salem WWTF	2003	7	23	1400		23	7.5	8	404	0.51	0.01499
MoDNR	1870/4.5	Spring Cr. 5.0 mi.bl. Salem WWTF	2003	7	23	1345		22.5	6.8	8	400	0.56	0.01499
MoDNR	1870/9.6	Spring Cr. 0.1 mi.ab. Salem WWTF	2003	8	27	610	0.05	24	5.4	7.8	461	0.33	0.01499
MoDNR	1870/9.5	Salem WWTF	2003	8	27	600		24	3	7.6	822		
MoDNR	1870/8.5	Spring Cr. 1.0 mi.bl. Salem WWTF	2003	8	27	630	2.54	21	5.1	7.7	583	0.51	0.01499
MoDNR	1870/9.6	Spring Cr. 0.1 mi.ab. Salem WWTF	2003	8	27	1300		27	18.8	8.7	839	0.32	0.01499
MoDNR	1870/9.5	Salem WWTF	2003	8	27	1250		30	5.7	7.7	823	1.33	0.08
MoDNR	1870/8.5	Spring Cr. 1.0 mi.bl. Salem WWTF	2003	8	27	1315		22	6.6	8	586	0.3	0.01499
MoDNR	1870/5.3	Spring Cr. 4.2 mi.bl. Salem WWTF	2003	8	27	650	2.66	23.5	4.8	7.7	502	0.53	0.01499
MoDNR	1870/4.5	Spring Cr. 5.0 mi.bl. Salem WWTF	2003	8	27	625	4.02	23	5	7.8	477	0.25	0.01499
MoDNR	1870/5.3	Spring Cr. 4.2 mi.bl. Salem WWTF	2003	8	27	1300		24	6.4	7.4	496	0.65	0.01499
MoDNR	1870/4.5	Spring Cr. 5.0 mi.bl. Salem WWTF	2003	8	27	1330		24	6.6	7.2	474	0.57	0.01499
MoDNR	1870/9.6	Spring Cr. 0.1 mi.ab. Salem WWTF	2003	8	28	605		24	4.9	7.8	454	0.34	0.01499
MoDNR	1870/9.5	Salem WWTF	2003	8	28	620		24	3.5	7.8	904		
MoDNR	1870/8.5	Spring Cr. 1.0 mi.bl. Salem WWTF	2003	8	28	630		21	4.5	8	584	0.58	0.01499
MoDNR	1870/5.3	Spring Cr. 4.2 mi.bl. Salem WWTF	2003	8	28	700		23	4.9	8	467	0.14	0.01499
MoDNR	1870/4.5	Spring Cr. 5.0 mi.bl. Salem WWTF	2003	8	28	650		22	4.9	7.8	453	0.02499	0.09
MoDNR	1870/9.6	Spring Cr. 0.1 mi.ab. Salem WWTF	2003	8	28	1230		27	16	8.6	440	0.3	0.01499
MoDNR	1870/9.5	Salem WWTF	2003	8	28	1210		30	3	7.6	895	0.02499	0.11
MoDNR	1870/8.5	Spring Cr. 1.0 mi.bl. Salem WWTF	2003	8	28	1245		22	5.7	8.3	593	0.02499	0.01499
MoDNR	1870/5.3	Spring Cr. 4.2 mi.bl. Salem WWTF	2003	8	28	1340		24.5	6.7	8.1	468	0.44	0.01499
MoDNR	1870/4.5	Spring Cr. 5.0 mi.bl. Salem WWTF	2003	8	28	1320		24.5	7.1	7.9	453	0.32	0.01499
MoDNR	1871/14.8	Meramec R. @ MDC Short Bend CA	2004	8	3	1200	7.77	25.2	7.2	8.2	363		0.01499
MoDNR	1871/14.8	Meramec R. @ MDC Short Bend CA	2004	10	19	1245	11.2	15.6	7.9	8.2	386		0.01499
MoDNR	1871/14.8	Meramec R. @ MDC Short Bend CA	2005	3	23	1300	36.7	8.2	11.4	8.7	334		0.01499
MoDNR	1871/14.8	Meramec R. @ MDC Short Bend CA	2005	6	17	805	12.2	21.9	6.2	8.1	365		0.01499
MoDNR	1870/9.9	Spring Cr. @ Hwy. 32/72	2008	7	18	1035		22.9	2.8	7.7	1035	0.3	0.12
MoDNR	1870/11.7	Spring Cr. @ CR 416	2008	7	18	1100	0.2	23.6	6.3	7.5	1100	0.22	0.07
MoDNR	1870/12.2	Spring Cr. @ Hwy. 19	2008	7	18	1125		23.3	4.5	7.5	1125	0.18	0.07

See notes and definitions of abbreviations on page 36.

### B.1 Department Data continued (same dates and sites; additional analytes)

Org	Site	Site Name	Year	Month	Day	NO3N	TN	TP	TSS	VSS	Chl a	TRB	CBOD
MoDNR	1870/9.0	Spring Cr. 0.5 mi.bl. Salem WWTF	1985	7	18								
MoDNR	1870/9.45	Spring Cr. 50 yds bl. Salem WWTF	1985	7	18								
MoDNR	1870/4.5	Spring Cr. 5.0 mi.bl. Salem WWTF	1985	7	18								
MoDNR	1870/9.5	Salem WWTF	1985	7	18				800				
MoDNR	1870/8.5	Spring Cr. 1.0 mi.bl. Salem WWTF	1985	7	18								
MoDNR	1870/9.6	Spring Cr. 0.1 mi.ab. Salem WWTF	1985	7	18								
MoDNR	1870/9.6	Spring Cr. 0.1 mi.ab. Salem WWTF	1985	7	18				4				
MoDNR	1870/9.45	Spring Cr. 50 yds bl. Salem WWTF	1985	7	18				184				
MoDNR	1870/8.5	Spring Cr. 1.0 mi.bl. Salem WWTF	1985	7	18				14				
MoDNR	1870/9.0	Spring Cr. 0.5 mi.bl. Salem WWTF	1985	7	18				8				
MoDNR	1870/9.5	Salem WWTF	1985	7	19				3				
MoDNR	1870/9.6	Spring Cr. 0.1 mi.ab. Salem WWTF	2003	7	22	0.44	1	0.05	2.499	2.499	2.2		0.99
MoDNR	1870/9.5	Salem WWTF	2003	7	22								
MoDNR	1870/8.5	Spring Cr. 1.0 mi.bl. Salem WWTF	2003	7	22	5.76	6.5	0.83	9	2.499	2		0.99
MoDNR	1870/4.5	Spring Cr. 5.0 mi.bl. Salem WWTF	2003	7	22	2.68	3.44	0.29	12	2.499	0.9		0.99
MoDNR	1870/5.3	Spring Cr. 4.2 mi.bl. Salem WWTF	2003	7	22	2.91	3.67	0.31	10	2.499	1.3		0.99
MoDNR	1870/9.6	Spring Cr. 0.1 mi.ab. Salem WWTF	2003	7	22	0.41	1.27	0.09	6	2.499	17.9		
MoDNR	1870/9.5	Salem WWTF	2003	7	22	17.5	17.8	2.71	2.499	2.499			
MoDNR	1870/8.5	Spring Cr. 1.0 mi.bl. Salem WWTF	2003	7	22	5.66	5.68	0.78	8	2.499	1.5		
MoDNR	1870/5.3	Spring Cr. 4.2 mi.bl. Salem WWTF	2003	7	22	2.55	3.16	0.29	6	2.499	1.4		0.99
MoDNR	1870/4.5	Spring Cr. 5.0 mi.bl. Salem WWTF	2003	7	22	2.59	2.82	0.25	6	2.499	6.5		0.99
MoDNR	1870/9.6	Spring Cr. 0.1 mi.ab. Salem WWTF	2003	7	23	0.38	0.86	0.07	9	2.499	4.5		0.99
MoDNR	1870/9.5	Salem WWTF	2003	7	23								
MoDNR	1870/8.5	Spring Cr. 1.0 mi.bl. Salem WWTF	2003	7	23	6.81	7.68	0.92	11	2.499	0.8		0.99
MoDNR	1870/5.3	Spring Cr. 4.2 mi.bl. Salem WWTF	2003	7	23	2.41	3.02	0.29	7	2.499	1.5		0.99
MoDNR	1870/4.5	Spring Cr. 5.0 mi.bl. Salem WWTF	2003	7	23	2.12	2.63		9	2.499	1		0.99
MoDNR	1870/9.6	Spring Cr. 0.1 mi.ab. Salem WWTF	2003	7	23	0.33	0.86	0.07	7	2.499	13.7		0.99
MoDNR	1870/9.5	Salem WWTF	2003	7	23	18.5	19.5	3	8	6			0.99
MoDNR	1870/8.5	Spring Cr. 1.0 mi.bl. Salem WWTF	2003	7	23	6.23	6.98	0.86	9	2.499	1.8		0.99
MoDNR	1870/5.3	Spring Cr. 4.2 mi.bl. Salem WWTF	2003	7	23	2.33	2.84	0.27	8	2.499	1.4		0.99
MoDNR	1870/4.5	Spring Cr. 5.0 mi.bl. Salem WWTF	2003	7	23	2.06	2.62	0.23	9	2.499	1.1		0.99
MoDNR	1870/9.6	Spring Cr. 0.1 mi.ab. Salem WWTF	2003	8	27	0.29	0.62	0.06	12	6	5		
MoDNR	1870/9.5	Salem WWTF	2003	8	27								

Org	Site	Site Name	Year	Month	Day	NO3N	TN	TP	TSS	VSS	Chl a	TRB	CBOD
MoDNR	1870/8.5	Spring Cr. 1.0 mi.bl. Salem WWTF	2003	8	27	7.13	7.64	4.38	9	5	2.1		
MoDNR	1870/9.6	Spring Cr. 0.1 mi.ab. Salem WWTF	2003	8	27	0.23	0.55	0.07	8	5	4.2		0.99
MoDNR	1870/9.5	Salem WWTF	2003	8	27	16.6	17.9	0.49	7	7			
MoDNR	1870/8.5	Spring Cr. 1.0 mi.bl. Salem WWTF	2003	8	27	6.94	7.24	1.19	8	2.499	4.1		0.99
MoDNR	1870/5.3	Spring Cr. 4.2 mi.bl. Salem WWTF	2003	8	27	3.76	4.29	0.45	10	5	1.5		0.99
MoDNR	1870/4.5	Spring Cr. 5.0 mi.bl. Salem WWTF	2003	8	27	3.13	3.38	0.38	9	2.499	1.3		0.99
MoDNR	1870/5.3	Spring Cr. 4.2 mi.bl. Salem WWTF	2003	8	27	3.52	4.17	0.44	6	2.499	2		0.99
MoDNR	1870/4.5	Spring Cr. 5.0 mi.bl. Salem WWTF	2003	8	27	3.06	3.63	0.35	5	2.499	3.3		0.99
MoDNR	1870/9.6	Spring Cr. 0.1 mi.ab. Salem WWTF	2003	8	28	0.33	0.67	0.04	8	5	2.1		2.23
MoDNR	1870/9.5	Salem WWTF	2003	8	28								
MoDNR	1870/8.5	Spring Cr. 1.0 mi.bl. Salem WWTF	2003	8	28	6.84	7.38	1.12	8	2.499	2		0.99
MoDNR	1870/5.3	Spring Cr. 4.2 mi.bl. Salem WWTF	2003	8	28	3.18	3.32	0.46	9	2.499	1.6		0.99
MoDNR	1870/4.5	Spring Cr. 5.0 mi.bl. Salem WWTF	2003	8	28	2.9	2.9	0.39	10	2.499	1.4		0.99
MoDNR	1870/9.6	Spring Cr. 0.1 mi.ab. Salem WWTF	2003	8	28	0.28	0.58	0.05	8	2.499	2.7		0.99
MoDNR	1870/9.5	Salem WWTF	2003	8	28	17.5	17.5	2.67	7	2.499			0.99
MoDNR	1870/8.5	Spring Cr. 1.0 mi.bl. Salem WWTF	2003	8	28	7.06	7.08	1.17	11	2.499	3.1		0.99
MoDNR	1870/5.3	Spring Cr. 4.2 mi.bl. Salem WWTF	2003	8	28	3.03	3.47	0.46	13	2.499	2		0.99
MoDNR	1870/4.5	Spring Cr. 5.0 mi.bl. Salem WWTF	2003	8	28	2.78	3.1	0.38	10	2.499	1.8		0.99
MoDNR	1871/14.8	Meramec R. @ MDC Short Bend CA	2004	8	3	0.04	0.12	0.00499					
MoDNR	1871/14.8	Meramec R. @ MDC Short Bend CA	2004	10	19	0.01	0.09	0.02					
MoDNR	1871/14.8	Meramec R. @ MDC Short Bend CA	2005	3	23	0.05	0.09	0.00499					
MoDNR	1871/14.8	Meramec R. @ MDC Short Bend CA	2005	6	17	0.06	0.07	0.00499					
MoDNR	1870/9.9	Spring Cr. @ Hwy. 32/72	2008	7	18	0.03	0.33	0.08	5			4.99	2.1
MoDNR	1870/11.7	Spring Cr. @ CR 416	2008	7	18	0.41	0.65	0.08	2.499			4.99	2.41
MoDNR	1870/12.2	Spring Cr. @ Hwy. 19	2008	7	18	0.18	0.36	0.16	3.75			4.99	0.99

See notes and definitions of abbreviations on next page.

Additional information regarding the available Spring Creek water quality data:

Sampling Entity	Type of Data	Used for Modeling?
MoDNR	QA	No
Tetra Tech, Inc. (under contract with EPA)	QA	Yes (See Section 5)
Salem WWTF	Screening	No
Stream Team	Screening	No

Notes:

- QA or Quality Assurance = These data are of sufficient quality to evaluate compliance with water quality standards and to support TMDL development because they were collected in accordance with required quality assurance procedures and MODNR sampling protocols.
- Screening = These data can only be used for screening purposes (i.e., not to evaluate compliance with water quality standards or to support TMDL development).
- All measurements are in milligrams per liter (mg/L) unless otherwise noted
- Empty cell means no data available.
- Detection limits and non-detects were expressed as "less-than" numbers and show up in this list as those data ending in 99. Examples: <2 appears as 0.99; <5 appears as 2.499

C = temperature in degrees Celsius

CA = Conservation Area

CBOD or CBOD5 = Carbonaceous Biochemical Oxygen Demand (5 days)

Chl a = Chlorophyll a (micrograms per liter or µg/L)

Cr. = Creek

CR = County Road

DO = Dissolved Oxygen

Flow is in cubic feet per second (cfs or ft<sup>3</sup>/s)

MDC = Missouri Department of Conservation

NH3N or NH3 = Ammonia as Nitrogen

NO2+NO3 or NO3N = Nitrite + Nitrate as Nitrogen

R. = River

SC = Specific Conductivity (micro mhos per centimeter)

Temp. = Temperature

TKN = Total Kjeldahl Nitrogen

TN = Total Nitrogen

TP = Total Phosphorus

TRB = Turbidity in NTU

TSS = Total Suspended Solids

VSS = Volatile Suspended Solids

## Appendix B.2

### Instream data collected by Salem WWTF (Permit MO-0021768) from 2/2007 to 1/2009

Location	Date	Parameter	Value
Downstream of WWTF Outfall	2/28/2007	DO (mg/L)	8.9
Downstream of WWTF Outfall	2/28/2007	NH3 (mg/L)	0.005
Downstream of WWTF Outfall	2/28/2007	pH	7.6
Downstream of WWTF Outfall	2/28/2007	Temperature (Celsius)	9.8
Upstream of WWTF Outfall	2/28/2007	DO (mg/L)	9
Upstream of WWTF Outfall	2/28/2007	NH3 (mg/L)	0.005
Upstream of WWTF Outfall	2/28/2007	pH	7.6
Upstream of WWTF Outfall	2/28/2007	Temperature (Celsius)	10
Downstream of WWTF Outfall	3/31/2007	DO (mg/L)	3.8
Downstream of WWTF Outfall	3/31/2007	NH3 (mg/L)	0.08
Downstream of WWTF Outfall	3/31/2007	pH	7.3
Downstream of WWTF Outfall	3/31/2007	Temperature (Celsius)	11.6
Upstream of WWTF Outfall	3/31/2007	DO (mg/L)	4.5
Upstream of WWTF Outfall	3/31/2007	NH3 (mg/L)	0.02
Upstream of WWTF Outfall	3/31/2007	pH	7.3
Upstream of WWTF Outfall	3/31/2007	Temperature (Celsius)	11.8
Downstream of WWTF Outfall	4/30/2007	DO (mg/L)	7.6
Downstream of WWTF Outfall	4/30/2007	NH3 (mg/L)	0.04
Downstream of WWTF Outfall	4/30/2007	pH	7.3
Downstream of WWTF Outfall	4/30/2007	Temperature (Celsius)	17.2
Upstream of WWTF Outfall	4/30/2007	DO (mg/L)	7.8
Upstream of WWTF Outfall	4/30/2007	NH3 (mg/L)	0.01
Upstream of WWTF Outfall	4/30/2007	pH	7.5
Upstream of WWTF Outfall	4/30/2007	Temperature (Celsius)	17
Downstream of WWTF Outfall	5/31/2007	DO (mg/L)	5.3
Downstream of WWTF Outfall	5/31/2007	NH3 (mg/L)	0.01
Downstream of WWTF Outfall	5/31/2007	pH	7.3
Downstream of WWTF Outfall	5/31/2007	Temperature (Celsius)	19.7
Upstream of WWTF Outfall	5/31/2007	DO (mg/L)	3.3
Upstream of WWTF Outfall	5/31/2007	NH3 (mg/L)	0.02
Upstream of WWTF Outfall	5/31/2007	pH	7.2
Upstream of WWTF Outfall	5/31/2007	Temperature (Celsius)	19.7
Downstream of WWTF Outfall	6/30/2007	DO (mg/L)	2.4
Downstream of WWTF Outfall	6/30/2007	NH3 (mg/L)	3.68
Downstream of WWTF Outfall	6/30/2007	pH	7.1
Downstream of WWTF Outfall	6/30/2007	Temperature (Celsius)	19
Upstream of WWTF Outfall	6/30/2007	DO (mg/L)	3.1
Upstream of WWTF Outfall	6/30/2007	NH3 (mg/L)	0.19
Upstream of WWTF Outfall	6/30/2007	pH	7.2
Upstream of WWTF Outfall	6/30/2007	Temperature (Celsius)	19.3
Downstream of WWTF Outfall	7/31/2007	DO (mg/L)	2.4

Location	Date	Parameter	Value
Downstream of WWTF Outfall	7/31/2007	NH3 (mg/L)	0.005
Downstream of WWTF Outfall	7/31/2007	pH	7.1
Downstream of WWTF Outfall	7/31/2007	Temperature (Celsius)	19
Upstream of WWTF Outfall	7/31/2007	DO (mg/L)	3.1
Upstream of WWTF Outfall	7/31/2007	NH3 (mg/L)	0.005
Upstream of WWTF Outfall	7/31/2007	pH	7.2
Upstream of WWTF Outfall	7/31/2007	Temperature (Celsius)	19.3
Downstream of WWTF Outfall	8/31/2007	DO (mg/L)	4.5
Downstream of WWTF Outfall	8/31/2007	NH3 (mg/L)	0.07
Downstream of WWTF Outfall	8/31/2007	pH	7.3
Downstream of WWTF Outfall	8/31/2007	Temperature (Celsius)	23.5
Upstream of WWTF Outfall	8/31/2007	DO (mg/L)	2
Upstream of WWTF Outfall	8/31/2007	NH3 (mg/L)	0.03
Upstream of WWTF Outfall	8/31/2007	pH	7.1
Upstream of WWTF Outfall	8/31/2007	Temperature (Celsius)	24.7
Downstream of WWTF Outfall	9/30/2007	DO (mg/L)	4.4
Downstream of WWTF Outfall	9/30/2007	NH3 (mg/L)	0.06
Downstream of WWTF Outfall	9/30/2007	pH	7.4
Downstream of WWTF Outfall	9/30/2007	Temperature (Celsius)	19
Upstream of WWTF Outfall	9/30/2007	DO (mg/L)	3.5
Upstream of WWTF Outfall	9/30/2007	NH3 (mg/L)	0.02
Upstream of WWTF Outfall	9/30/2007	pH	7.4
Upstream of WWTF Outfall	9/30/2007	Temperature (Celsius)	20
Downstream of WWTF Outfall	10/31/2007	DO (mg/L)	4.7
Downstream of WWTF Outfall	10/31/2007	NH3 (mg/L)	0.14
Downstream of WWTF Outfall	10/31/2007	pH	7.1
Downstream of WWTF Outfall	10/31/2007	Temperature (Celsius)	17.3
Upstream of WWTF Outfall	10/31/2007	DO (mg/L)	2.2
Upstream of WWTF Outfall	10/31/2007	NH3 (mg/L)	0.07
Upstream of WWTF Outfall	10/31/2007	pH	7
Upstream of WWTF Outfall	10/31/2007	Temperature (Celsius)	19.3
Downstream of WWTF Outfall	11/30/2007	DO (mg/L)	8.6
Downstream of WWTF Outfall	11/30/2007	NH3 (mg/L)	0.01
Downstream of WWTF Outfall	11/30/2007	pH	6.8
Downstream of WWTF Outfall	11/30/2007	Temperature (Celsius)	7.4
Upstream of WWTF Outfall	11/30/2007	DO (mg/L)	7.5
Upstream of WWTF Outfall	11/30/2007	NH3 (mg/L)	0.005
Upstream of WWTF Outfall	11/30/2007	pH	6.6
Upstream of WWTF Outfall	11/30/2007	Temperature (Celsius)	6
Downstream of WWTF Outfall	12/31/2007	DO (mg/L)	8.8
Downstream of WWTF Outfall	12/31/2007	NH3 (mg/L)	0.01
Downstream of WWTF Outfall	12/31/2007	pH	6.8
Downstream of WWTF Outfall	12/31/2007	Temperature (Celsius)	6.9
Upstream of WWTF Outfall	12/31/2007	DO (mg/L)	8.8
Upstream of WWTF Outfall	12/31/2007	NH3 (mg/L)	0.02
Upstream of WWTF Outfall	12/31/2007	pH	6.4
Upstream of WWTF Outfall	12/31/2007	Temperature (Celsius)	5.7

Location	Date	Parameter	Value
Downstream of WWTF Outfall	1/31/2008	DO (mg/L)	8.7
Downstream of WWTF Outfall	1/31/2008	NH3 (mg/L)	0.005
Downstream of WWTF Outfall	1/31/2008	pH	6.9
Downstream of WWTF Outfall	1/31/2008	Temperature (Celsius)	2.7
Upstream of WWTF Outfall	1/31/2008	DO (mg/L)	9.8
Upstream of WWTF Outfall	1/31/2008	NH3 (mg/L)	0.005
Upstream of WWTF Outfall	1/31/2008	pH	7
Upstream of WWTF Outfall	1/31/2008	Temperature (Celsius)	2.2
Downstream of WWTF Outfall	2/29/2008	DO (mg/L)	9.8
Downstream of WWTF Outfall	2/29/2008	NH3 (mg/L)	0.005
Downstream of WWTF Outfall	2/29/2008	pH	7.5
Downstream of WWTF Outfall	2/29/2008	Temperature (Celsius)	5.8
Upstream of WWTF Outfall	2/29/2008	DO (mg/L)	10.3
Upstream of WWTF Outfall	2/29/2008	NH3 (mg/L)	0.02
Upstream of WWTF Outfall	2/29/2008	pH	7.5
Upstream of WWTF Outfall	2/29/2008	Temperature (Celsius)	5.6
Downstream of WWTF Outfall	3/31/2008	DO (mg/L)	7.7
Downstream of WWTF Outfall	3/31/2008	NH3 (mg/L)	0.01
Downstream of WWTF Outfall	3/31/2008	pH	7.8
Downstream of WWTF Outfall	3/31/2008	Temperature (Celsius)	11
Upstream of WWTF Outfall	3/31/2008	DO (mg/L)	8.5
Upstream of WWTF Outfall	3/31/2008	NH3 (mg/L)	0.04
Upstream of WWTF Outfall	3/31/2008	pH	7
Upstream of WWTF Outfall	3/31/2008	Temperature (Celsius)	9.4
Downstream of WWTF Outfall	4/30/2008	DO (mg/L)	7.55
Downstream of WWTF Outfall	4/30/2008	NH3 (mg/L)	0.06
Downstream of WWTF Outfall	4/30/2008	pH	7.3
Downstream of WWTF Outfall	4/30/2008	Temperature (Celsius)	11
Upstream of WWTF Outfall	4/30/2008	DO (mg/L)	8.45
Upstream of WWTF Outfall	4/30/2008	NH3 (mg/L)	0.07
Upstream of WWTF Outfall	4/30/2008	pH	7.4
Upstream of WWTF Outfall	4/30/2008	Temperature (Celsius)	10.5
Downstream of WWTF Outfall	5/31/2008	DO (mg/L)	7.6
Downstream of WWTF Outfall	5/31/2008	NH3 (mg/L)	0.11
Downstream of WWTF Outfall	5/31/2008	pH	7.3
Downstream of WWTF Outfall	5/31/2008	Temperature (Celsius)	11
Upstream of WWTF Outfall	5/31/2008	DO (mg/L)	8.5
Upstream of WWTF Outfall	5/31/2008	NH3 (mg/L)	0.16
Upstream of WWTF Outfall	5/31/2008	pH	7.4
Upstream of WWTF Outfall	5/31/2008	Temperature (Celsius)	10.5
Downstream of WWTF Outfall	6/30/2008	DO (mg/L)	4.7
Downstream of WWTF Outfall	6/30/2008	NH3 (mg/L)	0.1
Downstream of WWTF Outfall	6/30/2008	pH	7.5
Downstream of WWTF Outfall	6/30/2008	Temperature (Celsius)	19.1
Upstream of WWTF Outfall	6/30/2008	DO (mg/L)	5
Upstream of WWTF Outfall	6/30/2008	NH3 (mg/L)	0.05
Upstream of WWTF Outfall	6/30/2008	pH	7.6

Location	Date	Parameter	Value
Upstream of WWTF Outfall	6/30/2008	Temperature (Celsius)	19.7
Downstream of WWTF Outfall	7/31/2008	DO (mg/L)	4.5
Downstream of WWTF Outfall	7/31/2008	NH3 (mg/L)	0.17
Downstream of WWTF Outfall	7/31/2008	pH	7.5
Downstream of WWTF Outfall	7/31/2008	Temperature (Celsius)	20.9
Upstream of WWTF Outfall	7/31/2008	DO (mg/L)	4.3
Upstream of WWTF Outfall	7/31/2008	NH3 (mg/L)	0.35
Upstream of WWTF Outfall	7/31/2008	pH	7.6
Upstream of WWTF Outfall	7/31/2008	Temperature (Celsius)	21.7
Downstream of WWTF Outfall	8/31/2008	DO (mg/L)	6.5
Downstream of WWTF Outfall	8/31/2008	NH3 (mg/L)	0.08
Downstream of WWTF Outfall	8/31/2008	pH	7.7
Downstream of WWTF Outfall	8/31/2008	Temperature (Celsius)	19.4
Upstream of WWTF Outfall	8/31/2008	DO (mg/L)	4.4
Upstream of WWTF Outfall	8/31/2008	NH3 (mg/L)	0.05
Upstream of WWTF Outfall	8/31/2008	pH	7.8
Upstream of WWTF Outfall	8/31/2008	Temperature (Celsius)	20.8
Downstream of WWTF Outfall	8/31/2008	DO (mg/L)	6.4
Downstream of WWTF Outfall	9/30/2008	NH3 (mg/L)	0.03
Downstream of WWTF Outfall	9/30/2008	pH	7.6
Downstream of WWTF Outfall	9/30/2008	Temperature (Celsius)	17.3
Upstream of WWTF Outfall	9/30/2008	DO (mg/L)	6
Upstream of WWTF Outfall	9/30/2008	NH3 (mg/L)	0.04
Upstream of WWTF Outfall	9/30/2008	pH	7.7
Upstream of WWTF Outfall	9/30/2008	Temperature (Celsius)	17.5
Downstream of WWTF Outfall	10/31/2008	DO (mg/L)	5.3
Downstream of WWTF Outfall	10/31/2008	NH3 (mg/L)	0.03
Downstream of WWTF Outfall	10/31/2008	pH	7.6
Downstream of WWTF Outfall	10/31/2008	Temperature (Celsius)	16.5
Upstream of WWTF Outfall	10/31/2008	DO (mg/L)	6
Upstream of WWTF Outfall	10/31/2008	NH3 (mg/L)	0.07
Upstream of WWTF Outfall	10/31/2008	pH	7.8
Upstream of WWTF Outfall	10/31/2008	Temperature (Celsius)	15
Downstream of WWTF Outfall	11/30/2008	DO (mg/L)	5.7
Downstream of WWTF Outfall	11/30/2008	NH3 (mg/L)	0.01
Downstream of WWTF Outfall	11/30/2008	pH	7.6
Downstream of WWTF Outfall	11/30/2008	Temperature (Celsius)	13.6
Upstream of WWTF Outfall	11/30/2008	DO (mg/L)	5.4
Upstream of WWTF Outfall	11/30/2008	NH3 (mg/L)	0.01
Upstream of WWTF Outfall	11/30/2008	pH	7.9
Upstream of WWTF Outfall	11/30/2008	Temperature (Celsius)	12.7
Downstream of WWTF Outfall	12/31/2008	DO (mg/L)	9
Downstream of WWTF Outfall	12/31/2008	NH3 (mg/L)	0.07
Downstream of WWTF Outfall	12/31/2008	pH	7.9
Downstream of WWTF Outfall	12/31/2008	Temperature (Celsius)	4.9
Upstream of WWTF Outfall	12/31/2008	DO (mg/L)	11.5
Upstream of WWTF Outfall	12/31/2008	NH3 (mg/L)	0.03

<b>Location</b>	<b>Date</b>	<b>Parameter</b>	<b>Value</b>
Upstream of WWTF Outfall	12/31/2008	pH	8.3
Upstream of WWTF Outfall	12/31/2008	Temperature (Celsius)	4.2
Downstream of WWTF Outfall	1/31/2009	DO (mg/L)	9.8
Downstream of WWTF Outfall	1/31/2009	NH3 (mg/L)	0.05
Downstream of WWTF Outfall	1/31/2009	pH	7.4
Downstream of WWTF Outfall	1/31/2009	Temperature (Celsius)	2.3
Upstream of WWTF Outfall	1/31/2009	DO (mg/L)	12.8
Upstream of WWTF Outfall	1/31/2009	NH3 (mg/L)	0.06
Upstream of WWTF Outfall	1/31/2009	pH	7.4
Upstream of WWTF Outfall	1/31/2009	Temperature (Celsius)	1.9

### Appendix B.3

Water Quality Data collected by Volunteer Water Quality Monitors trained to Level II through the Missouri Stream Team Program

Date	Site	Rainfall	Weather	Time	Air Temp	Water Temp	DO	pH	Nitrate	Conductivity	PO4	Turbidity
9/29/2007	1		Sunny	9:40	15	15	2	6.8	0.25	340	0.22	<10
9/29/2007	2		Sunny	10:00	16	16	4	7.4	10	660	3.3	<10
12/14/2007	2		Cloudy	14:00	10	5	10	7.6	4	370	1.6	Clear
4/4/2008	2	Several Inches	Partly Cloudy/Chilly	14:30	6	10	10	6.1	0.25	210	0.59	12
9/29/2007	3		Sunny	11:00	20	19	8	7.8	<0.25	500	0.21	12
12/14/2007	3		Cloudy		4	4	12	7.5	0.5	320	0.14	Murky
4/4/2008	3	Several Inches	Partly Cloudy/Chilly	15:15	8	10	10	6.5	0.25	160	0.29	23
9/29/2007	4		Clear	12:00	17	18	6	7.5	0.25	390	0.16	40
12/14/2007	4		Cloudy		5	5	12	7.3	0.5	280	0.02	Clear
4/4/2008	4	Several Inches	Partly Cloudy/Chilly	15:45	8	10	5	6.9	0.25	160	0.14	20
9/29/2007	5		Clear	12:40	22	20	5	7.6	0.25	430	0.19	10
12/14/2007	5		Partly Cloudy	16:00	2	5	10	6.9	0.5	290	0.12	Murky
4/4/2008	5	Several Inches	Partly Cloudy/Chilly	16:30	8	10	8		0.25	250	0.28	12
9/29/2007	6		Clear	13:30	25	21	4	7.3	0.25	320	0.33	15
12/14/2007	6		Partly Cloudy		1	5	11	7	0.25	270	0.33	Murky/Stagnant
4/4/2008	6	Several Inches	Partly Cloudy/Chilly	16:50	10	10	7	7.2	0.25	190	0.38	20

Units: Temp in degrees Celsius, Dissolved Oxygen, Nitrate and PO<sub>4</sub> (phosphate) in mg/L, Conductivity in µS/cm, Turbidity in NTU, US = upstream, DS = downstream, CR = County Road

Note: 12/14/07 – Turbidity: subjective information (no turbidity tube). 4/4/08 – high water levels following two weeks of flooding; woody debris and sand deposited. Site 1 – dump site: engine block, couch, mattress and dead dog at this location.

#### Site descriptions (map on next page):

Site 1 – North of Site 2 on CR 322 near gravel road bridge (off map). This creek was determined to be a tributary to Spring Creek and, because of that, was dropped as a monitoring site.

Site 2 – US of CR 322 bridge approx 2 miles north of Hwy J.

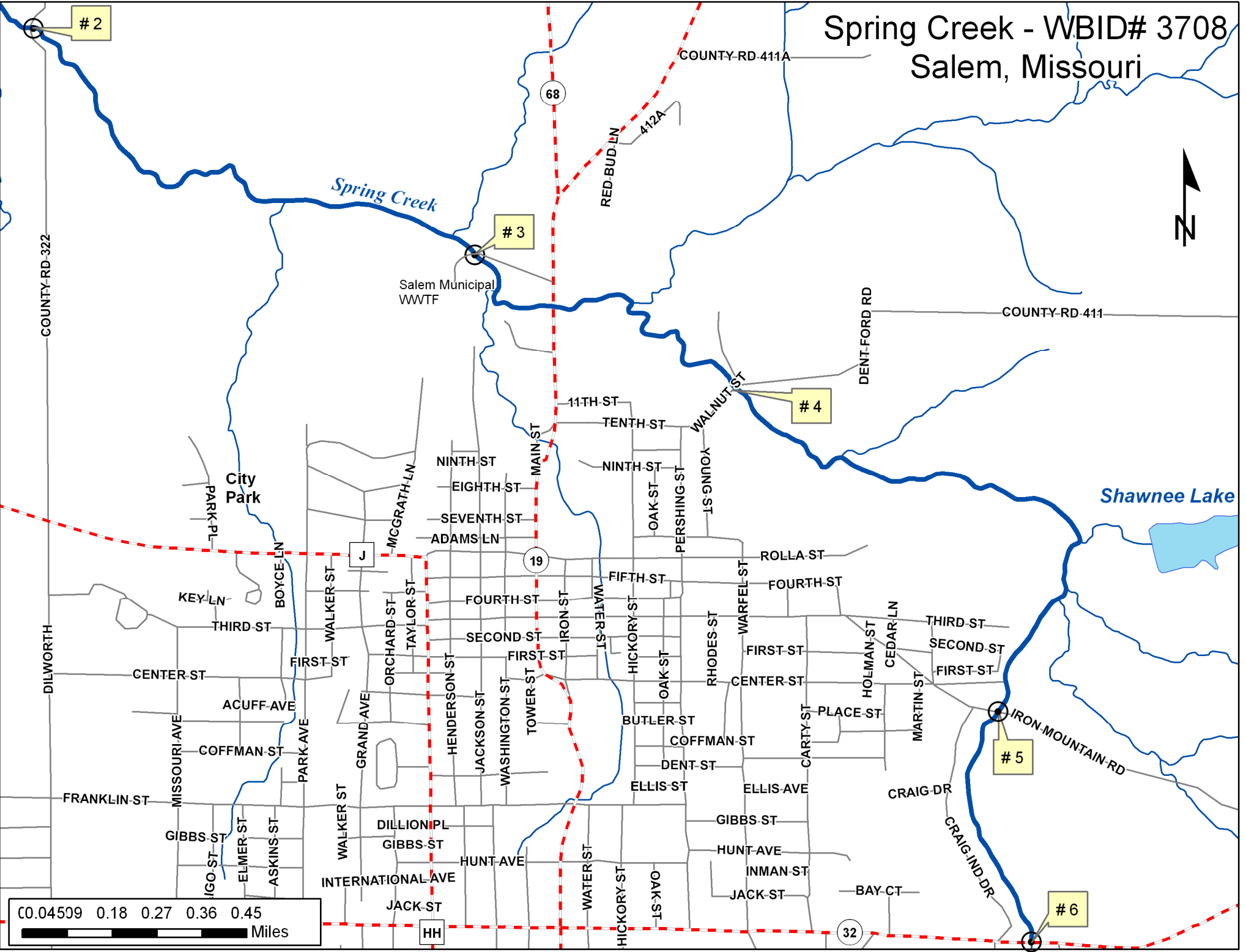
Site 3 – Just US of low water bridge at WWTF (US of WWTF)

Site 4 – Just DS of 10<sup>th</sup> St bridge (also called Dent's Ford Rd)

Site 5 – CR 416, US of bridge

Site 6 – Rt 32, just E. of MFA, N. side (DS) of bridge.

Spring Creek - WBID# 3708  
Salem, Missouri



## Appendix C

### Spring Creek QUAL2K Modeling

#### I. Modeling Approach

TetraTech data from the 2008 stream water quality sampling at Spring Creek were used to develop the QUAL2K model described below. Though there were two sampling events (5/29 & 9/3) conducted in 2008, the data collected during September were not used for model validation because this event was not representative of the critical flow condition.

##### 1.1 Hydraulics/Hydrology

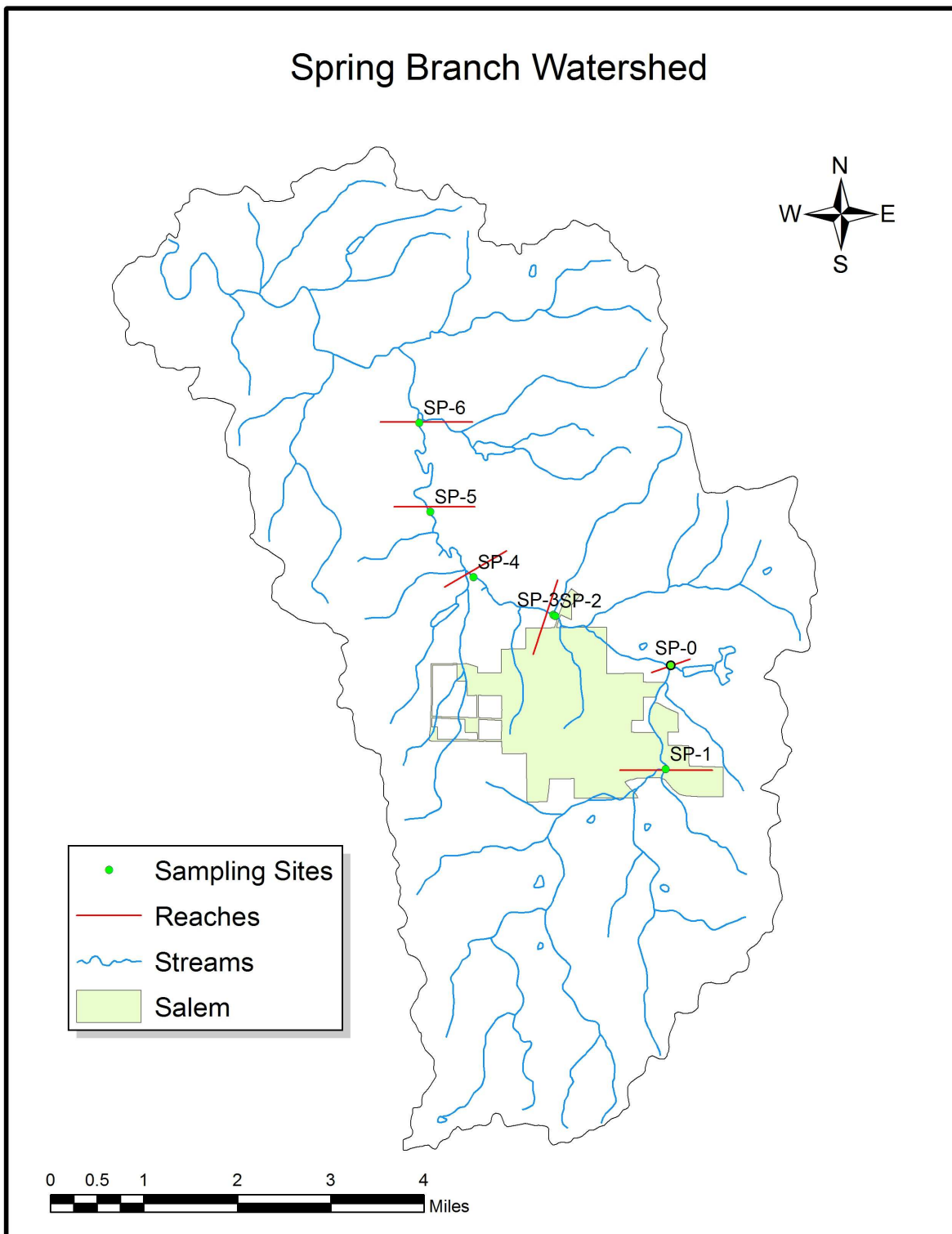
a. Hydraulic geometry relations (or rating curve equations) were developed from the flow measurements collected at four sites (SP1, SP2, SP4, and SP5) on Spring Creek on May 28, 2008 (Figure C.1). These hydrologic relationships between depth (H, m) and velocity (U, m/s), and streamflow (or discharge, Q, m<sup>3</sup>/s) were used to calibrate the hydrology of QUAL2K model (Table C.1). The entire stream modeled was 10.35 km. The data collected at Site SP6 were not used because they were collected from a pool habitat.

**Table C.1. Rating curve equations used in the QUAL2K model.**

	Velocity (m/s)		Depth (m)	
	Coefficient	Exponent	Coefficient	Exponent
SP1, SP2, SP4, SP5	0.5354	0.1244	0.2152	0.8632

b. The hydrology of SP1 was used as the upstream boundary condition. SP0 was added to create two reaches between SP1 and SP2. Four stream reaches (SP1-SP0, SP0-SP2, SP2-SP4, and SP4-SP5) were modeled with the focus on the latter two reaches (SP2-SP4, and SP4-SP5). Site SP3 was an effluent outlet location (6.34 km upstream from SP6) of Salem's wastewater treatment facility (WWTF). For this model, all tributaries were treated as non-point sources, because there were no sufficient water quality data and these streams either were dried or had very little flow, except one treated as a point source. This stream entered Spring Creek at SP0 (8.37 km) to account for all subsurface flow induced by a nearby impoundment.

Figure C.1. Sampling locations of Spring Creek Watershed.



## 1.2 Water Quality

a. The water quality (WQ) values were parameterized and calibrated using the water chemistry data collected from SP1, SP2, SP3, SP4, and SP5 as well as the continuous diurnal dissolved oxygen (DO) and water temperature measurements recorded at SP4. The WQ data of SP1 were used as the upstream boundary condition. Table C.2 shows the measured WQ data measured at the sampling sites.

**Table C.2. Summary of Spring Creek's WQ data collected on May 29, 2008.**

Sampling Location (Time)	Location	Chlorophyll <i>a</i> (µg/L)	CBOD <sub>5</sub> (mg/L)	Nitrogen, Ammonia (mg/L)	Nitrogen, TKN (mg/L)	Nitrogen, NO <sub>2</sub> +NO <sub>3</sub> (mg/L)	DO (mg/L)	pH	Temp. (°C)	TP (mg/L)	TSS (mg/L)
SP1 (8:30AM)	2.5 mi above WWTF	7	1.00	0.23	BDL	0.11	6.31	6.40	17.38	0.006	10
SP2 (9:45AM)	0.02 mi above WWTF	5	1.00	0.16	BDL	0.31	5.55	6.95	18.26	0.006	12
SP3 (9:25AM)	Salem WWTF Effluent	No Data	1.00	0.01	BDL	15.30	6.78	7.40	19.01	2.500	5
SP4 (11:30AM)	1.1 mi below WWTF	3	1.00	0.17	BDL	3.50	5.67	7.46	No Data	0.450	6
SP5 (2:00PM)	2.3 mi below WWTF	2	1.00	0.13	1.10	2.40	7.64	7.22	17.22	0.280	17

Notes: CBOD<sub>5</sub> = Carbonaceous Biochemical Oxygen Demand (5 days); TKN = Total Kjeldahl Nitrogen; NO<sub>2</sub>+NO<sub>3</sub> = Nitrite + Nitrate; DO = Dissolved Oxygen; Temp. = Temperature; TP = Total Phosphorus; TSS = Total Suspended Solids; BDL = Below Detection Limit.

- b. The model was calibrated by adjusting the kinetic rates such that the measured WQ parameters and the diurnal DO were reasonably simulated.
- c. Using the calibrated model, a waste load allocation (WLA) scenario was simulated for Spring Creek, based on the ecoregion nutrient concentrations (Ecoregion 39, U.S. EPA, 2000). The simulation was performed to determine the reduction needed in both nutrients and BOD to meet the DO standard (5.0 mg/l) upstream and downstream of the Salem WWTF. The conditions used in the scenario as follows:

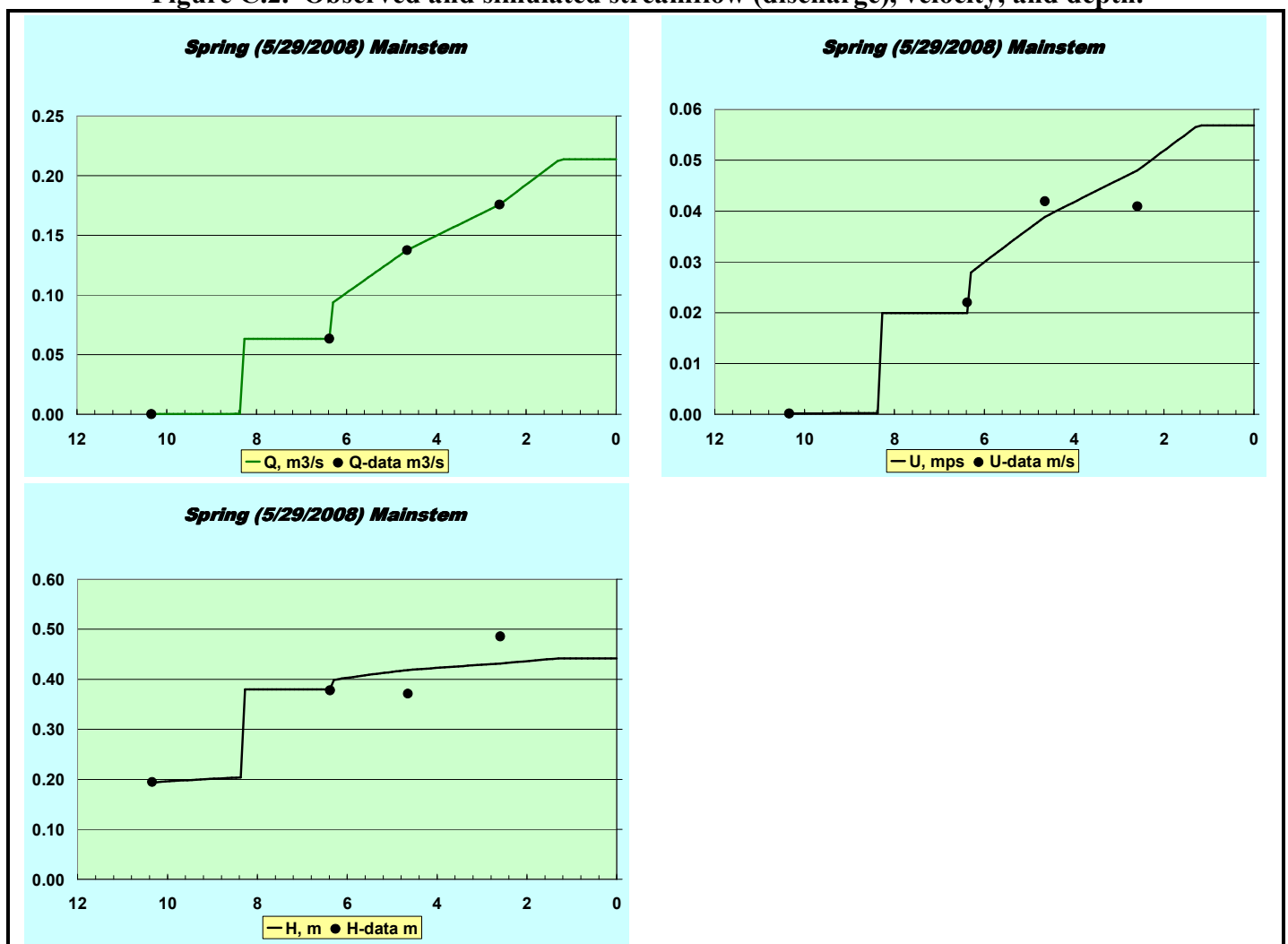
*WWTF design flow; 7Q10 headwater (or boundary) flow; TN = 0.289 mg/L, TP = 0.007 mg/L for both Salem WWTF and headwater (SP1); CBOD<sub>5</sub> = 1 mg/L and Chlorophyll *a* = 1 µg/L for the headwater; Chlorophyll *a* = 1 µg/L for the WWTF; no point sources and subsurface flow; August 4 weather data (hottest day in the summer, Cook station, Crawford County).*

## II. Model Results

### 2.1 Hydraulics/Hydrology

Figure C.2 shows the calibration results of the flow, depth and velocity using the stream data collected on May 29, 2008. The streamflow data were reasonably simulated for all the sites. Likewise, the simulated stream depth and velocity matched with the observed data for SP1 and SP2. Some variations were observed for SP4 and SP5 because the reach-wide hydro-morphologic (rating curve, see Table C.1) equations were used as a result of the limited hydrologic data measured at the sampling sites.

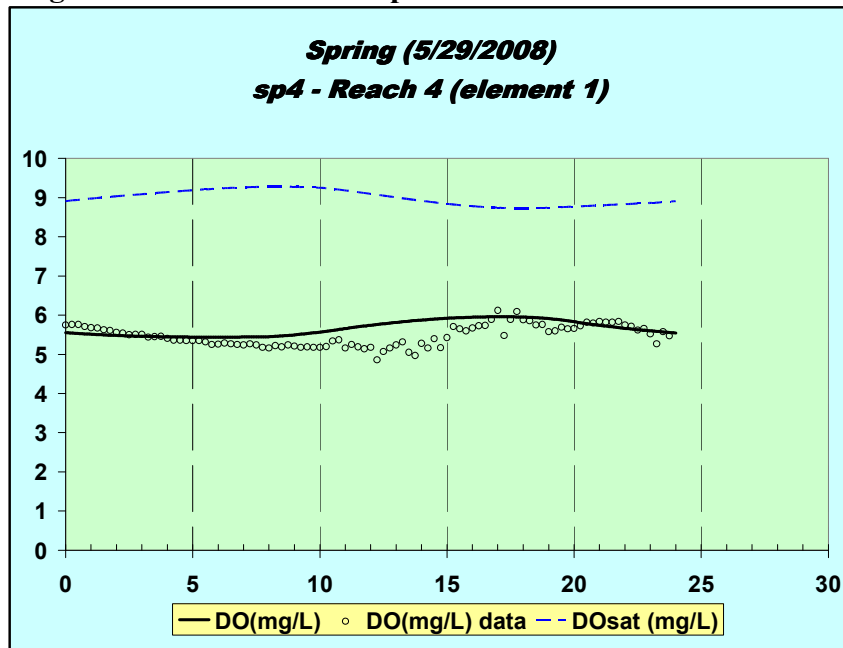
Figure C.2. Observed and simulated streamflow (discharge), velocity, and depth.



## 2.2 Water Quality

- a. The comparison of observed and predicted diurnal DO at SP4 is shown in Figure C.3. The predicted DO values seem to reasonably capture most of the actual DO variations at site SP4.

**Figure C.3. Observed and predicted diurnal DO at site SP4.**



- b. The predicted longitudinal profile of DO is shown in Figure C.4. The large DO sag from upstream boundary to about 8.37 km was an artifact of model setting as an initial condition for reach SP1-SP0. As indicated in Figure C.4, the effluent discharged from Salem's WWTF, though decreasing the DO values downstream, was not the primary contributing factor to cause the DO impairment in the modeled reaches of Spring Creek. Other calibrated parameters are shown in Figure C.5.

Figure C.4. Predicted and observed longitudinal DO profile.

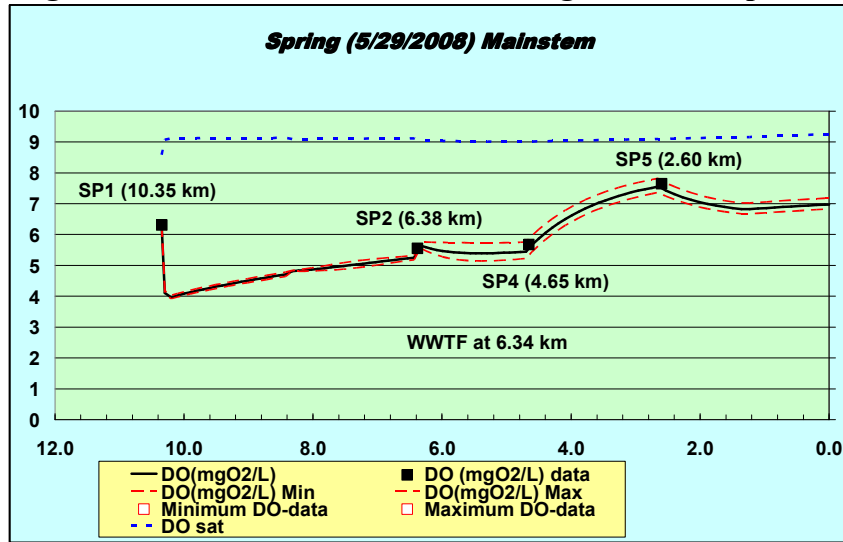


Figure C.5. Predicted and observed WQ profiles including pH, nutrients, and phytoplankton.

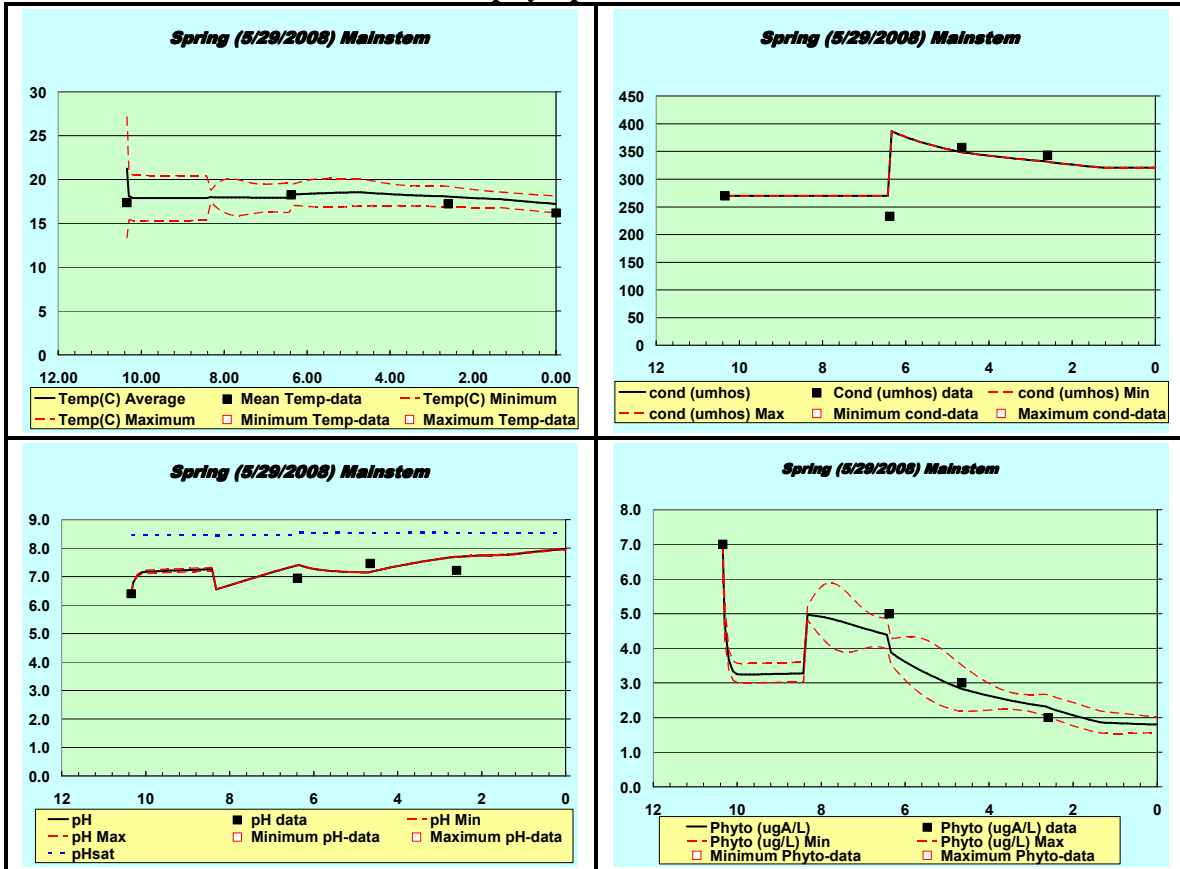
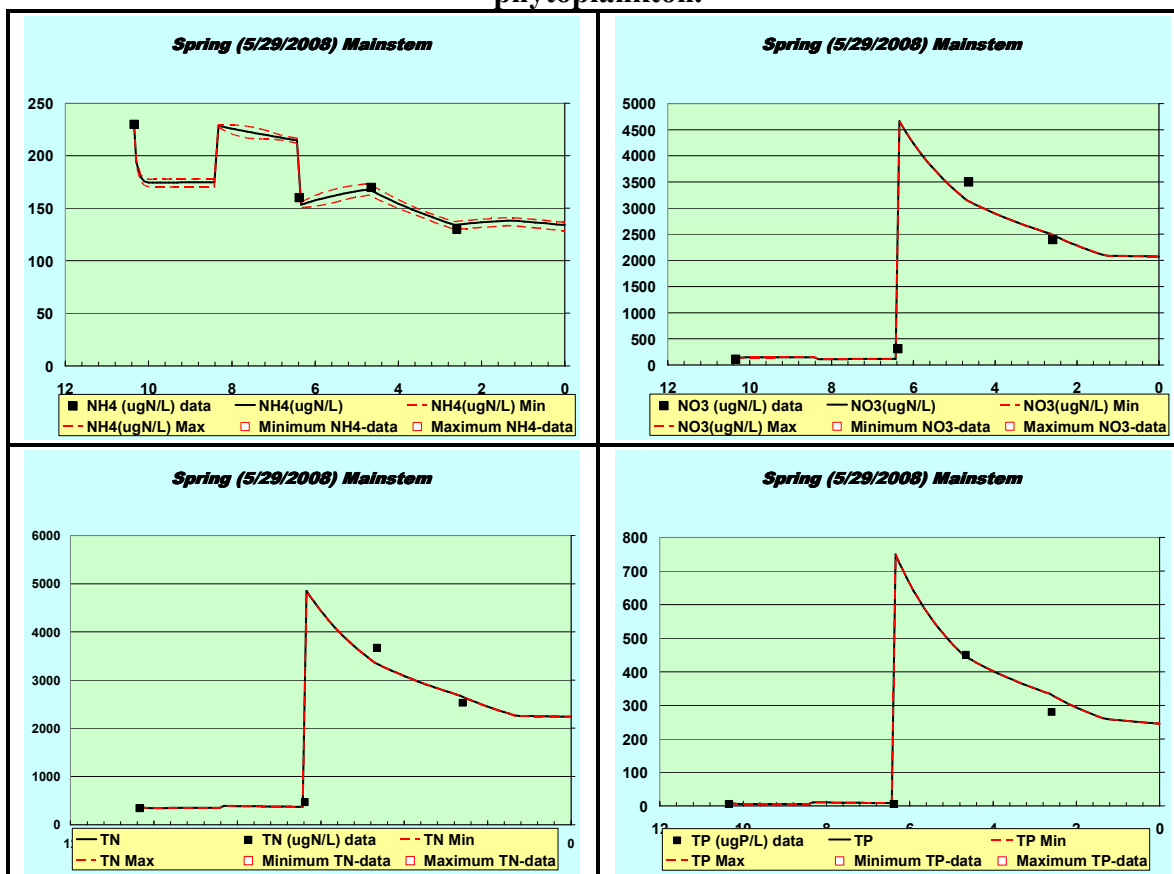
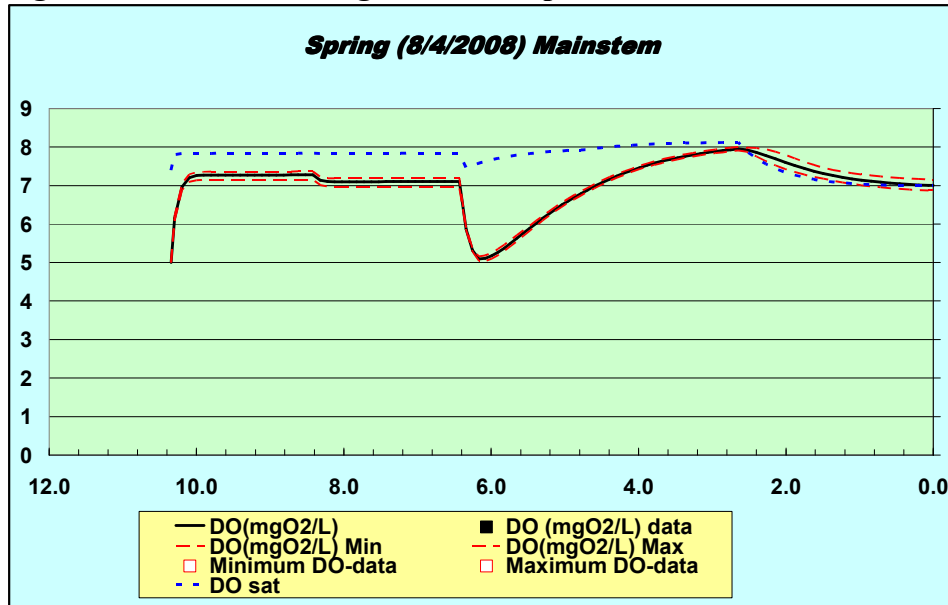


Figure C.5 (cont). Predicted and observed WQ profiles including pH, nutrients, and phytoplankton.



c. Figure C.6 shows the predicted longitudinal DO profile from the WLA simulation, with diagenesis function turned on. For the downstream sites of Salem's WWTF to meet the DO standard, 5 mg/L, the minimum BOD<sub>5</sub> is 3.3 mg/L when the WWTF's nitrogen and phosphorous levels, along with the headwater nutrients, are set to the reference stream concentrations.

Figure C.6. Predicted longitudinal DO profile of the WLA simulation.



## Reference

U.S. EPA. 2000. Ambient Water Quality Criteria Recommendations: Rivers and Streams in Nutrient Ecoregion XI. U.S. Environmental Protection Agency, Washington DC. EPA 822-B-00-020.

## **Appendix D**

### **Development of Suspended Sediment Targets using Reference Load Duration Curves**

#### **Overview**

This procedure is used when a lotic<sup>14</sup> system is placed on the 303(d) List for a pollutant and the designated use being addressed is aquatic life. In cases where pollutant data for the impaired stream is not available a reference approach is used. The target for pollutant loading is the 25<sup>th</sup> percentile calculated from all data available within the ecological drainage unit (EDU) in which the water body is located. Additionally, it is also unlikely that a flow record for the impaired stream is available. If this is the case, a synthetic flow record is needed. In order to develop a synthetic flow record calculate an average of the log discharge per square mile of USGS gaged rivers for which the drainage area is entirely contained within the EDU. From this synthetic record develop a flow duration from which to build a load duration curve for the pollutant within the EDU.

From this population of load durations follow the reference method used in setting nutrient targets in lakes and reservoirs. In this methodology the average concentration of either the 75<sup>th</sup> percentile of reference lakes or the 25<sup>th</sup> percentile of all lakes in the region is targeted in the TMDL. For most cases available pollutant data for reference streams is also not likely to be available. Therefore follow the alternative method and target the 25<sup>th</sup> percentile of load duration of the available data within the EDU as the TMDL load duration curve. During periods of low flow the actual pollutant concentration may be more important than load. To account for this during periods of low flow the load duration curve uses the 25<sup>th</sup> percentile of EDU concentration at flows where surface runoff is less than 1 percent of the stream flow. This result in an inflection point in the curve below which the TMDL is calculated using load calculated with this reference concentration.

#### **Methodology**

The first step in this procedure is to locate available pollutant data within the EDU of interest. These data along with the instantaneous flow measurement taken at the time of sample collection for the specific date are recorded to create the population from which to develop the load duration. Both the date and pollutant concentration are needed in order to match the measured data to the synthetic EDU flow record.

Secondly, collect average daily flow data for gages with a variety of drainage areas for a period of time to cover the pollutant record. From these flow records normalize the flow to a per square mile basis. Average the log transformations of the average daily discharge for each day in the period of record. For each gage record used to build this synthetic flow record calculate the Nash-Sutcliffe statistic to determine if the relationship is valid for each record. This relationship must be valid in order to use this methodology. This new synthetic record of flow per square

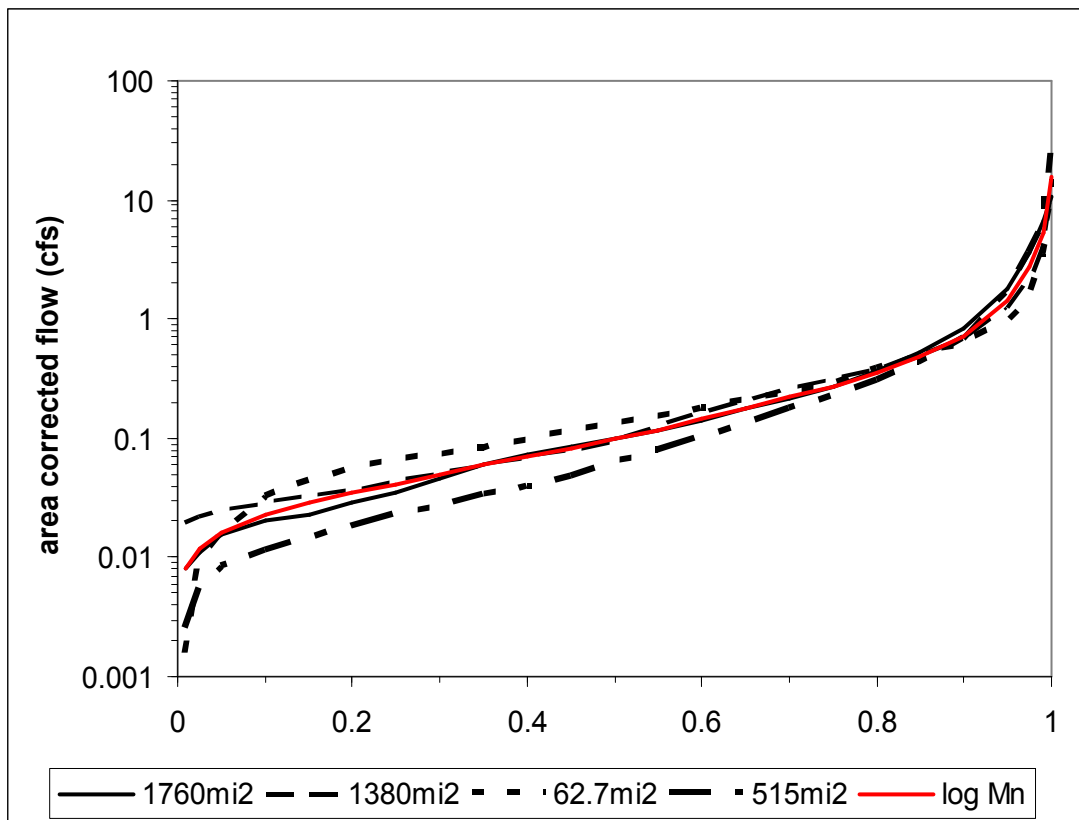
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<sup>14</sup> Lotic = pertaining to moving water

mile is used to develop the load duration for the EDU. The flow record should be of sufficient length to be able to calculate percentiles of flow.

The following examples show the application of the approach to one Missouri EDU.

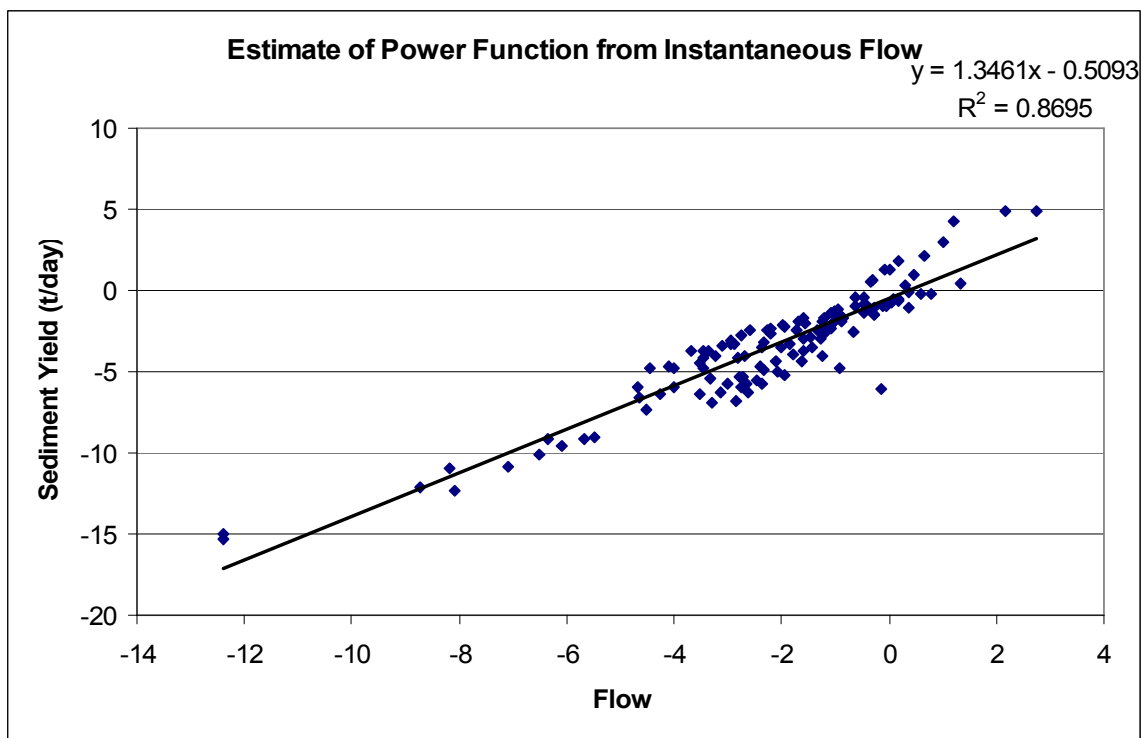
The watershed-size normalized data for the individual gages in the EDU were calculated and compared to a pooled data set including all of the gages. The results of this analysis are displayed in the following figure and table:



Gage	gage	area (mi <sup>2</sup> )	normal Nash-Sutcliffe	lognormal Nash-Sutcliffe
Platte River	06820500	1760	80%	99%
Nodaway River	06817700	1380	90%	96%
Squaw Creek	06815575	62.7	86%	95%
102 River	06819500	515	99%	96%

This demonstrates the pooled data set can confidently be used as a surrogate for the EDU analyses.

The next step is to calculate pollutant-discharge relationships for the EDU, these are log transformed data for the yield (tons/mi<sup>2</sup>/day) and the instantaneous flow (cfs/mi<sup>2</sup>.) The following graph shows the EDU relationship:



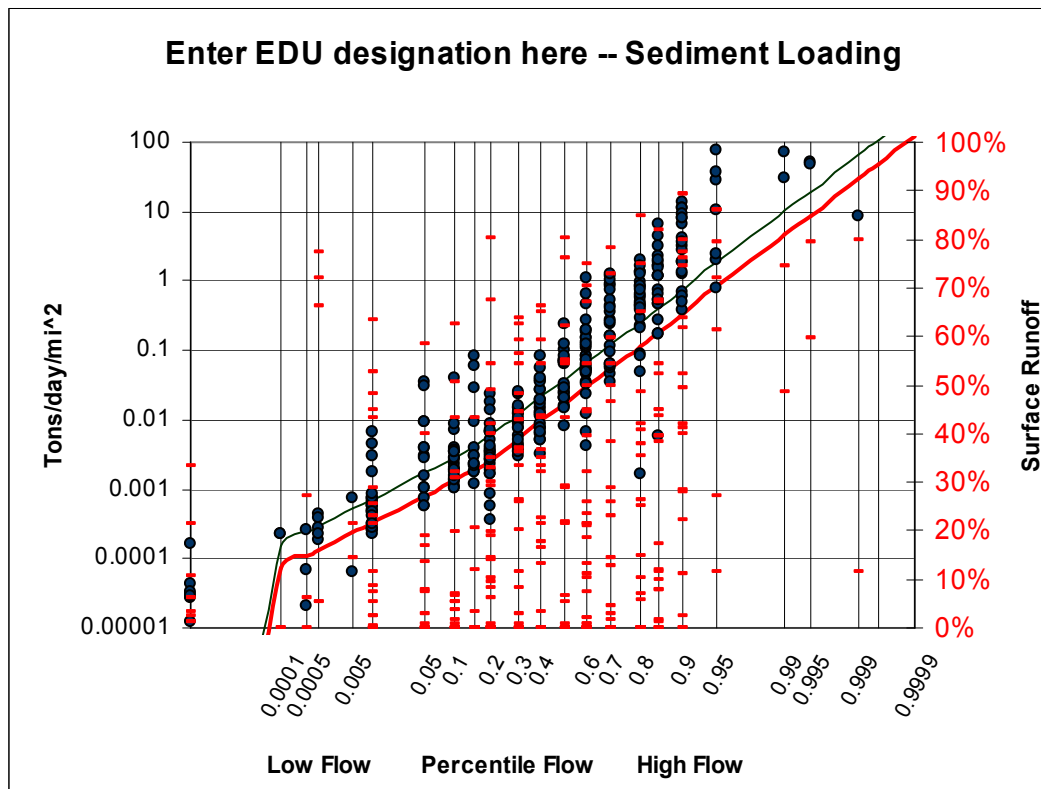
Further statistical analyses on this relationship are included in the following Table:

m	1.34608498	b	-0.509320019
Standard Error (m)	0.04721684	Standard Error (b)	0.152201589
r <sup>2</sup>	0.86948229	Standard Error (y)	1.269553159
F	812.739077	DF	122
SSreg	1309.94458	SSres	196.6353573

The standard error of y was used to estimate the 25 percentile level for the TMDL line. This was done by adjusting the intercept (b) by subtracting the product of the one-sided  $Z_{75}$  statistic times the standard error of (y). The resulting TMDL Equation is the following:

$$\text{Sediment yield (t/day/mi}^2\text{)} = \exp (1.34608498 * \ln (\text{flow}) - 1.36627)$$

A resulting pooled TMDL of all data in the watershed is shown in the following graph:



To apply this process to a specific watershed would entail using the individual watershed data compared to the above TMDL curve that has been multiplied by the watershed area. Data from the impaired segment is then plotted as a load (tons/day) for the y-axis and as the percentile of flow for the EDU on the day the sample was taken for the x-axis.

For more information contact:  
Environmental Protection Agency, Region 7  
Water, Wetlands, and Pesticides Division  
Total Maximum Daily Load Program  
901 North 5<sup>th</sup> Street  
Kansas City, Kansas 66101  
website: <http://www.epa.gov/region07/water/tmdl.htm>

**Appendix E**  
**Total suspended solids and instantaneous discharge for reference targeting.**

Gasconade River (06930800)			Courtois Creek (07014200)		
Date	TSS (mg/L)	Discharge (cfs)	Date	TSS (mg/L)	Discharge (cfs)
11/6/1997	4	885	1/19/1994	2	77
1/21/1998	13	1970	6/23/1994	14	82
6/18/1998	20	2910	1/12/1995	6	85
8/3/1998	27	3310	6/7/1995	12	186
6/24/1999	1	921	1/17/1996	1	62
8/12/1999	5	642	1/29/1997	2	413
1/13/2000	2	722	6/19/1997	2	313
7/5/2000	14	493	1/12/1998	3	226
5/3/2001	14	681	5/9/2002	73	3250
7/18/2001	13	547			
11/19/2001					
1	12	469			
12/4/2001	34	1820			
3/26/2002	54	8780			
5/20/2002	69	26100			
7/16/2002	10	729			
5/8/2003	71	4900			
11/21/2003					
3	154	13600			
1/20/2004	31	5910			
2/4/2004	21	2730			
3/10/2004	12	5690			
11/18/2004					
4	10	1820			
12/10/2004					
4	39	7740			
5/8/2006	24	5860			
1/23/2007	19	7240			
4/25/2007	10	3360			
5/8/2007	12	2930			
7/11/2007	25	1360			
9/10/2007	15	1890			
1/9/2008	260	8130			
2/6/2008	62	7290			
3/18/2008	246	25800			
4/2/2008	100	22900			
6/3/2008	41	2470			

Gasconade River (06930800)			Courtois Creek (07014200)		
Date	TSS (mg/L)	Discharge (cfs)	Date	TSS (mg/L)	Discharge (cfs)
8/4/2008	16	1080			
5/18/2009	18	6440			
7/6/2009	24	1150			
11/2/2009	85	37400			

Jacks Fork River (07066110)			Huzzah Creek (07014000)		
Date	TSS (mg/L)	Discharge (cfs)	Date	TSS (mg/L)	Discharge (cfs)
11/12/1992	15	2200	1/19/1994	2	142
1/22/1993	10	1200	6/23/1994	6	175
4/7/1993	9	1100	1/13/1995	8	352
5/17/1993	7	500	6/7/1995	12	285
6/3/1993	3	366	1/29/1997	1	576
7/9/1993	6	274	6/19/1997	2	310
10/20/1993	1	375	1/12/1998	3	200
1/5/1994	2	402	6/14/1999	1	153
6/15/1994	20	498	11/1/2001	58	57
6/19/1995	8	554	5/9/2002	49	3050
1/29/1996	1	326			
6/10/1996	1	361			
6/10/1997	4	410			
1/13/1998	4	520			
1/26/1999	1	530			
5/13/2002	36	2400			
2/14/2007	18	2400			
4/3/2007	10	440			

Maramec Spring (07010500)			Black River (07061600)		
Date	TSS (mg/L)	Discharge (cfs)	Date	TSS (mg/L)	Discharge (cfs)
1/20/1994	8	135	11/13/2001	12	114

Maramec Spring (07010500)			Black River (07061600)		
Date	TSS (mg/L)	Discharge (cfs)	Date	TSS (mg/L)	Discharge (cfs)
6/23/1994	8	135	5/14/2002	36	6630
1/13/1995	4	285	11/18/2000	3	174
6/7/1995	4	254	11/23/2000	4	13
1/30/1997	3	307	1/4/2006	14	203
6/19/1997	6	384	1/29/2006	103	1140
3/15/2004	11	208	4/18/2006	10	268
			5/11/2006	71	6830
			4/3/2007	20	990
			9/10/2007	13	1020

Meramec River (07014500)			Meramec River (07014500)		
Date	TSS (mg/L)	Discharge (cfs)	Date	TSS (mg/L)	Discharge (cfs)
7/14/1977	32	343	10/18/1985	4	508
8/4/1977	11	190	11/22/1985	34	5330
9/8/1977	30	248	12/12/1985	78	10900
10/13/1977	16	324	1/10/1986	1	966
12/15/1977	48	3640	2/13/1986	9	1390
1/4/1978	5	504	3/13/1986	2	1210
2/6/1978	3	330	4/10/1986	11	1630
3/7/1978	57	775	5/16/1986	26	2660
4/6/1978	4	1160	2/6/1987	5	788
5/16/1978	14	1470	3/5/1987	11	1670
6/15/1978	10	388	4/9/1987	8	834
7/26/1978	27	678	5/14/1987	8	714
8/24/1978	3	275	7/9/1987	53	1240
9/14/1978	6	250	8/13/1987	9	320
10/26/1978	2	375	10/8/1987	3	286
11/30/1978	2	1210	11/5/1987	1	357
12/20/1978	2	480	12/9/1987	53	3720
1/23/1979	11	1610	1/14/1988	1	872
3/15/1979	15	925	2/4/1988	27	3350
4/10/1979	52	1370	3/4/1988	53	5060
5/24/1979	6	2070	4/8/1988	26	2190
6/20/1979	7	520	5/19/1988	5	651
7/25/1979	5	291	6/3/1988	7	531
8/23/1979	27	391	7/14/1988	7	521

Meramec River (07014500)			Meramec River (07014500)		
Date	TSS (mg/L)	Discharge (cfs)	Date	TSS (mg/L)	Discharge (cfs)
9/19/1979	1	290	8/5/1988	2	323
10/18/1979	4	305	9/15/1988	6	260
11/29/1979	16	437	12/7/1988	11	837
12/20/1979	0.5	295	1/13/1989	1	1220
1/18/1980	4	350	2/9/1989	1	1030
2/22/1980	8	792	3/15/1989	18	2350
3/21/1980	8	1500	4/5/1989	31	4030
4/4/1980	20	1270	5/5/1989	36	793
5/8/1980	3	520	6/7/1989	1	677
6/5/1980	8	377	7/20/1989	3	428
7/10/1980	206	240	8/4/1989	9	409
8/14/1980	21	223	9/13/1989	2	351
9/18/1980	10	215	12/4/1989	1	314
10/9/1980	4	198	1/18/1990	18	445
11/6/1980	2	268	2/13/1990	6	1470
1/8/1981	4	248	3/20/1990	10	2090
2/12/1981	220	406	4/10/1990	6	1250
3/5/1981	4	450	5/8/1990	138	2860
4/9/1981	5	520	6/4/1990	12	1800
5/7/1981	1	400	12/10/1992	5	501
6/5/1981	20	2000	1/19/1993	30	1450
7/9/1981	12	630	3/15/1993	1	1200
8/6/1981	10	1220	4/8/1993	15	2090
9/4/1981	17	1260	5/19/1993	76	5020
10/7/1981	9	300	6/1/1993	6	870
11/5/1981	60	9600	7/6/1993	26	833
12/2/1981	22	2500	8/12/1993	7	6830
1/7/1982	1	1300	9/30/1993	16	3210
2/18/1982	148	19400	10/6/1993	13	1640
3/11/1982	9	577	11/3/1993	8	1070
4/7/1982	4	899	1/20/1994	4	1010
6/16/1982	7	1250	6/23/1994	12	966
7/16/1982	5	473	8/31/1994	16	811
8/11/1982	5	460	11/2/1994	6	456
9/24/1982	2	756	6/12/1995	40	4620
11/5/1982	3	611	8/2/1995	22	592
12/1/1982	13	2550	11/21/1995	2	410
12/15/1982	1	1750	1/22/1996	7	1440
1/7/1983	6	1420	8/20/1996	2	490
2/1/1983	2	752	11/13/1996	6	1640

Meramec River (07014500)			Meramec River (07014500)		
Date	TSS (mg/L)	Discharge (cfs)	Date	TSS (mg/L)	Discharge (cfs)
3/10/1983	5	1260	1/14/1997	2	670
4/20/1983	7	2060	6/17/1997	29	2220
5/13/1983	15	1860	8/6/1997	12	410
6/14/1983	5	762	11/12/1997	2	684
8/18/1983	3	281	1/23/1998	5	828
11/17/1983	5	810	8/6/1998	16	1720
12/20/1983	7	1450	11/16/1998	1	739
1/18/1984	1	740	1/19/1999	33	3180
2/23/1984	5	1010	6/29/1999	10	1170
3/21/1984	60	4720	8/10/1999	56	1380
4/19/1984	8	1880	1/11/2000	2	517
5/10/1984	1	1940	5/14/2001	13	324
6/20/1984	10	720	7/25/2001	14	226
7/18/1984	3	496	3/28/2002	16	3000
8/15/1984	1	380	4/10/2002	20	1860
9/19/1984	5	586	5/23/2002	26	2800
10/11/1984	9	684	4/8/2003	25	1870
12/6/1984	6	1440	5/5/2003	46	2450
1/11/1985	5	1850	7/30/2003	10	351
2/21/1985	71	3180	5/4/2004	38	3140
3/14/1985	16	3630	11/3/2004	36	1570
4/4/1985	2	3560	8/17/2005	15	896
5/10/1985	8	2120	5/17/2006	10	1710
6/12/1985	48	8750	9/5/2006	10	206
7/12/1985	1	1060	4/2/2007	42	2660
8/7/1985	73	2230	5/21/2007	23	648
9/19/1985	5	532	2/6/2008	114	1950
6/12/1986	43	2430	3/25/2008	22	3270
7/11/1986	10	464	6/3/2008	13	903
8/27/1986	1	399	4/20/2009	89	10400
9/19/1986	12	592	10/29/2009	29	3870
10/23/1986	1	600			
11/21/1986	12	644			
12/18/1986	13	841			

## **Appendix F.**

### **USGS gaging sites used for synthetic flow development.**

Gage	Period of Record
USGS 07187000 Shoal Creek above Joplin, MO	10/1/1997 - 9/30/2009
USGS 07188653 Big Sugar Creek nr Powell, MO	5/25/1997 - 9/30/2009
USGS 07188838 Little Sugar Creek nr Pineville, MO	9/30/2004 - 9/30/2009
USGS 07188885 Indian Creek nr Lanagan, MO	5/24/1997 - 9/30/2009
USGS 07189000 Elk River nr Tiff City, MO	10/1/1997 - 9/30/2009